COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 12, No. 9 MARCH, 1941 25c a copy

Welders at work on tubes around burners in pulverized-coal furnace

Baltimore Initiates Expansion Program With 25,000-Kw Topping Unit

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VOLUME TWELVE NUMBER NINE

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FOR MARCH 1941

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EDITORIALS

DEPARTMENTS

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EDITORIAL

Meeting Power Demands for 1941 and 1942

The Federal Power Commission has just issued a report to the effect that in approximately half the power supply areas of the United States there is installed, or scheduled for operation this year, sufficient capacity to meet the anticipated demands for 1941. In some of the remaining areas the demands can be met by utilization of reserves and through existing interconnections with adjacent areas in which surplus capacity may be available. However, in those sections served largely by hydro, much will depend upon favorable stream flow conditions, which are difficult to forecast.

It is the situation in 1942 that the Commission views as less satisfactory, for the power demand appears to be growing more rapidly than was anticipated. This is indicated by the growth in demand in nine major defense-production areas, including New England, up-state New York, Philadelphia-New Jersey, western Pennsylvania, Ohio, Michigan, Alabama, Georgia and north central Texas, in which the average increase for three months exceeded the estimates by fifty-three per cent. In some the increases were nearly double the anticipated figures.

Despite the fact that between September and December 1940, the utilities ordered over nine hundred thousand kilowatts of additional generating capacity scheduled for operation by December 1942, the Commission estimates that a further eight hundred thousand kilowatts will be necessary by the end of next year to insure against power shortage. Some of this has been ordered since the first of the year and more is in various stages of projection and design.

It will be recalled that the additional generating capacity scheduled for completion this year by the utilities, as announced by the E.E.I. last January, amounts to 3,412,000 kilowatts, and 2,302,000 kilowatts in 1942. This would appear more than enough to meet the Commission's estimates, but because of the time lag between orders placed and dates of completion it is difficult to make comparisons between the Commission's figures and those of the E.E.I.

Presumably, the Federal Power Commission is in an advantageous position to correlate the power requirements, through its access to orders placed by the various defense agencies, and thus arrive at a reasonably close approximation of the power needed in the different manufacturing areas. To what extent it may have taken into account the increased capacity afforded by the many additions to industrial power plants identified with Government orders, is not apparent. This, however, represents a substantial amount.

The public utilities have responded splendidly to the defense requirements, even to the extent of risking the possibility of excess capacity when the present emergency has passed.

The situation is further strengthened by the very considerable individual power generating capacity on order for a number of large munitions plants now being constructed by the government. When the emergency is over this capacity will in no way affect the normal balance of supply and demand for power by industry.

Deferment for Engineers

It is now generally recognized that in the present stage of achieving adequate national defense, production takes precedence over military man power; also that production needs engineers. That the demand for men trained in engineering greatly exceeds the available supply is attested by several surveys which have been recently conducted. Therefore, it is both logical and expedient to avoid depletion of engineering personnel in industry through induction into the draft at the present time. Despite the contention that most young men are replaceable, it takes time to break in new men in most lines of engineering work and this, in the aggregate, tends to retard production.

In a recent radio address, Dr. Harvey N. Davis, President of Stevens Institute of Technology, stressed this point and appealed to draft boards to take cognizance of the present shortage of engineers in meeting the requirements of the defense industries by granting a deferred status to such men. Terming his talk "Priorities in Men," he argued that this was just as essential to the defense program as are priorities in the essential materials.

The Society for the Promotion of Engineering Education, with the backing of the A.S.M.E. and several engineering colleges, has proposed to the Government that the engineering schools continue without interruption through vacations so as to graduate seniors next January instead of June 1942. This will make available at an earlier date a considerable number of men with engineering training to meet the increasing needs of industry. To put this plan into effect it is proposed that Congress make funds available through the U. S. Office of Education to cover additional expense incident to the change. While these young men can hardly be considered as qualified engineers, and as indispensable to production as are those with several years' experience, they nevertheless will have had the benefit of technical training which will enable them speedily to fit into engineering work associated with defense.

If we are to profit by the lessons of 1917 and the more recent events abroad, those charged with the task of selection must exercise judgment in the utilization of the nation's man power.

BALTIMORE INITIATES

By H. N. BOETCHER and G. S. HARRIS

Consolidated Gas Electric Light and Power Company of Baltimore

The 25,000-kw superposed turbine-generator unit placed in service at Westport Station on August 10, 1940, was the first addition to the steam generating capacity of the Consolidated Gas Electric Light and Power Company of Baltimore since the second unit was installed at Gould Street Station in 1928. The facilities of this company are interconnected with those of the Safe Harbor Water Power Corporation, the Pennsylvania Water and Power Company and the Potomac Electric Power Company to permit the fullest utilization of hydroelectric plants and to obtain the best system economy in the installation and operation of steam generating units. The new unit improved the balance between firm steam generating capacity and demand. During the construction period, increasing load growth in the Baltimore area resulted in the ordering of a 50,000-kw condensing unit for operation at Westport Station in 1941 and an initial 50,000-kw condensing unit for operation at the new Riverside Station in 1942.

PRIOR to 1940, Westport Station contained eight condensing units with a total installed capacity of 157,500 kw, of which 40,000 kw was in two 60-cycle machines (installed in 1924) operating on a regenerative-cycle with extraction at three stages for feedwater heating. All units were supplied with steam at a pressure of 200 lb per sq in. and a total temperature of 540 F through a loop main.

Comprehensive studies indicated the installation of a 1250-lb, 900-F superposed turbine-generator exhausting into the existing 200-lb piping system and normally supplying the steam required by the two 60-cycle units. Removal of obsolete boiler plant permitted the installation of the new equipment adjacent to the low-pressure machines and provided additional space for future installations.

In the selection of equipment and arrangement of heat balance, advantage was taken of the experiences obtained in the operation of other high-pressure stations during recent years—information on which was generously supplied by all of the companies contacted. Emphasis was placed in the design upon dependability of operation and prompt restoration of service at the expense of some increase in investment and at the sacrifice of slight gains in economy. The combined capacity of the 25,000-kw superposed unit and two 20,000-kw low-pressure units amounts to 65,000 kw whereas the largest single unit on the system is 50,000 kw. To minimize the effect of an

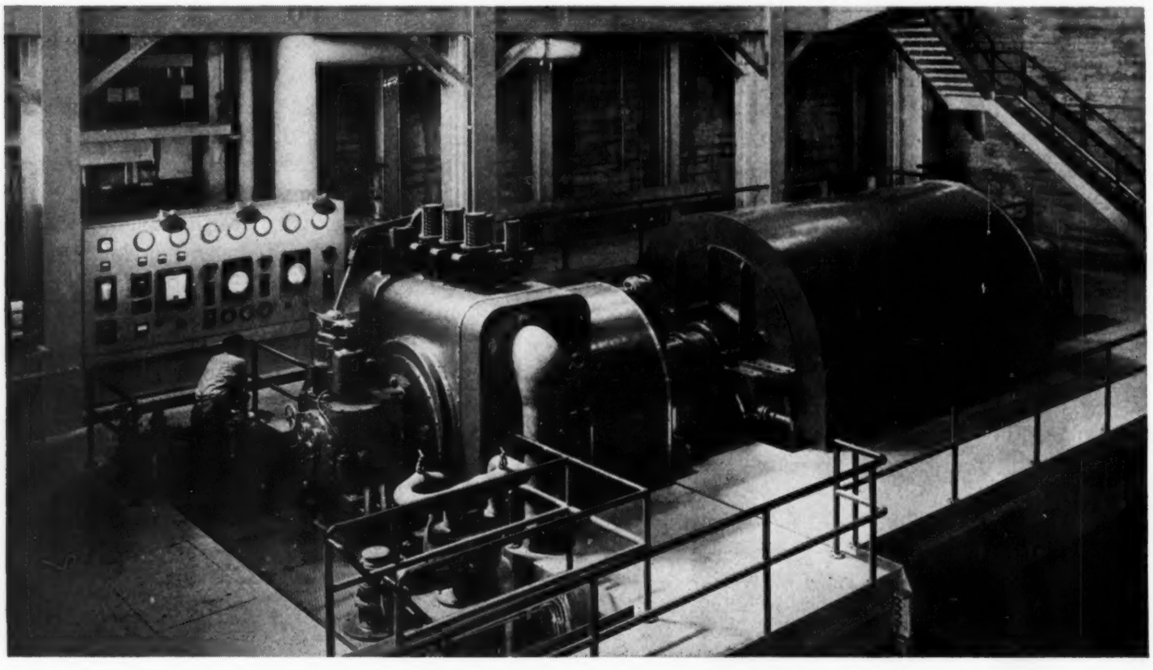

Fig. 1—25,000-kw superposed turbine generator.

EXPANSION PROGRAM
With 25,000-Kw Topping Unit

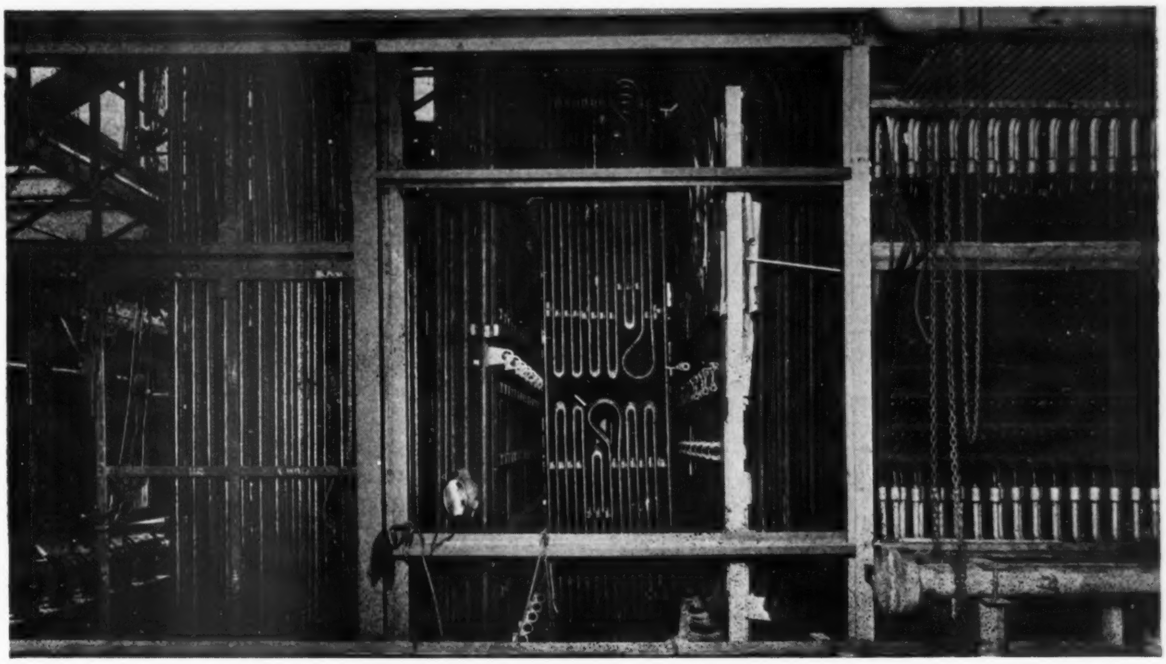

Fig. 2—Furnace walls, boiler tubes, superheater and economizer during construction

outage, two boilers were installed, thus reducing the possible loss of capacity by reason of the loss of one boiler to 35,000 kw. A pressure-reducing and desuperheating station was installed in the steam line from each boiler with quick-opening valves so arranged that, upon loss of the superposed unit, steam is automatically bypassed directly from the high-pressure boilers to the 200-lb header without interrupting supply to the low-pressure units.

The turbine-driven boiler-feed pumps, each of sufficient size to supply water to both boilers at maximum load, are located on the lowest level in the turbine room, convenient to an attendant. The pumps are a combination of the barrel and the split-casing types both of which have been used in high-pressure stations. A relatively light horizontally-split-casing pump is assembled in a forged-steel barrel to which the suction and discharge piping is connected. Suction is taken from a tank, containing a 12-minute supply of heated water, which is placed directly beneath the deaerating feedwater heater 88 ft above the pump.

Improved economy could be realized by heating the feedwater to 383 F with steam from the 200-lb header. However, without a margin between header and heater pressures an operating disturbance might cause a reduction of pressure in the heater which would result in flashing at the pumps. To obviate this possibility, steam in the heater is maintained at 90 lb per sq in., which is well below the limit of probable fluctuations. Consideration has been given to the installation of a closed heater on the discharge side of the pumps to raise the temperature of the boiler feedwater from 330 F to 383 F. However, because of a continuing need for low-pressure boiler capacity, a gain in economy would be obtained only for short periods and the additional investment cannot be justified at this time.

Boiler Plant

Each boiler is of the three-drum, bent-tube type rated at 285,000 lb per hr continuously when supplied with feedwater at 330 F and delivering steam at 1325 lb per sq in., 915 F total temperature; the overload capacity being 10 per cent for short periods. A pendant-type two-pass superheater is located in a downflow gas passage behind three rows of boiler tubes. Steam temperature is regulated by means of a damper, under the front upper drum, which bypasses a part of the gases directly from the first to the last gas passage in which is located the fin-tube economizer. Heat recovery is completed in a regenerative air preheater having a horizontal shaft.

The furnace is of fin tube construction throughout with a dry-type, water-cooled hopper bottom. Exposed refractories are practically eliminated. Four burners, arranged for the use of pulverized coal and oil, are located in the rear furnace wall under the lower drum. The two upper burners were placed 12 ft above the lower burners to improve the superheat at low boiler outputs. Mill and burner capacities were increased above those normally needed to facilitate this supplementary steam-temperature control. The furnace volume is 16,900

cu ft. At full load on the boiler the temperature of gases is 2000 F leaving the furnace and 1895 F entering the superheater, with a heat release rate of 22,300 Btu per cu ft.

Air is supplied to each furnace by a constant-speed motor-driven forced-draft fan having inlet-vane control. This air is preheated to 514 F at full load. An air by-pass around the preheater is provided to reduce the danger of condensation in the heater at low loads. Upon leaving the air preheater the gases pass through a Cottrell electrostatic precipitator to an induced-draft fan which is driven by a variable-speed a-c motor and equipped with an outlet damper for regulation between speed-control points and at low loads. The two induced-draft fans discharge to a common steel stack, lined with $2^1/_2$-in. of Gunite, erected on steel supports above the precipitators.

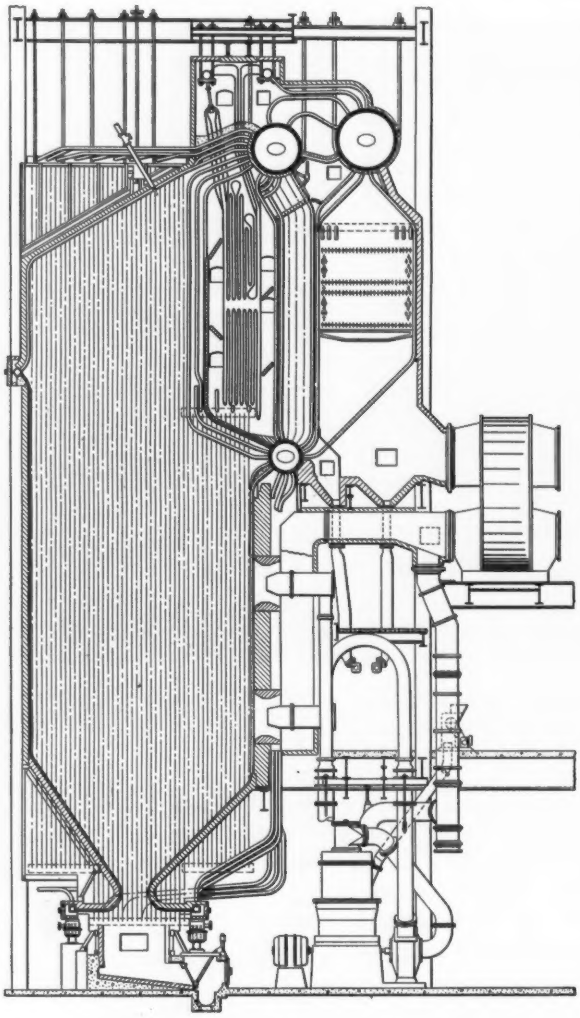

Fig. 3—Cross-section of steam-generating unit

A system of belt conveyors receives crushed coal from previously existing unloading and reclaiming equipment and delivers it to a suspended steel bunker. The mill feeders are driven by variable-speed d-c motors fitted with rheostats regulated automatically by the combustion-control system. Each furnace is supplied with pulverized coal by two bowl-type mills with capacity to maintain full load on the boiler under adverse conditions of moisture and grindability.

Furnace-bottom ash is handled through an hydraulic sluice. Dust from the precipitators and from hoppers under the economizers is transported by a pneumatic conveyor to a silo equipped with a cyclone separator, bag filters for vented-air and with dustless unloaders which deliver wetted material either to trucks or railroad cars.

Turbine Plant

The turbine-generator is a 25,000-kw, 3600-rpm, non-condensing, air-cooled machine with direct-connected exciter. The turbine is of the double-casing, single-cylinder type with 14 stages, designed to receive steam at 1250 lb per sq in., 900 F total temperature and to exhaust at 205 lb per sq in. With the double-casing construction the only parts of the outer shell subjected to the initial pressure and temperature are the relatively small control-valve casings. Ten control valves are mounted in the shell—five in the upper half and five in the lower.

The generator is rated at 31,250-kva, 0.8 power factor and unity short-circuit ratio. Excitation is at 250 volts. This machine is the first to be put into operation with the laminated core mounted on radially disposed spring bars to confine vibration to its source and eliminate 120-cycle noise and transmitted vibrations (1, 2).[1]

The foundation consists essentially of a massive block of concrete with a heavy substructure of concrete on wood piles and with openings between piers for exhaust piping under the turbine, generator air-coolers and electric leads. Cantilever constructions have been avoided and shock-absorbing material has been used at the base of columns erected on the mat to support walkways and platforms.

Piping

The piping layout does not differ, in general, from other superposed installations. It comprises the high-pressure steam piping for supplying the main unit, the boiler-feed-pump turbines and the reducing stations; the 200-lb steam piping to take the steam from the turbines and the reducing stations to the existing station header; the low-pressure boiler-feed piping to deaerator and boiler-feed pumps; the high-pressure boiler-feed piping from

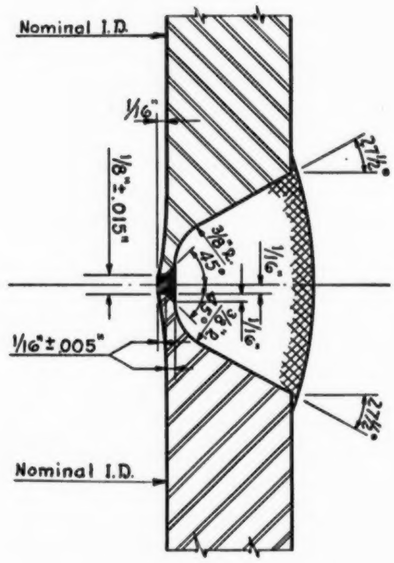

Fig. 4—Pipe-to-pipe joint

[1] Numbers refer to references at end of description.

pumps to economizer; and the usual miscellaneous service and instrument piping.

The high-pressure steam piping from the boilers connects to a header from which the supply lines for main and boiler-feed-pump turbines are taken. A pressure-reducing and desuperheating station is connected to each boiler lead through a forged tee ahead of the stop valve adjacent to the header. This arrangement makes it possible to bring up a second boiler and parallel it on the header after both steam pressure and temperature have been equalized.

The two boiler-feed pumps are connected to a short header from which the supply lines to the boilers are taken. The feed-control valves are of the Smoot type with three-element Bailey control. No auxiliary headers or boiler supply lines have been provided. However, bypasses branch off the supply lines to the boilers ahead of the automatic feed valves and pass to the ends of the economizer headers opposite the main inlets. Each bypass line is equipped with a hand-operated globe valve so located that the operator can watch steam and water flow meters on the boiler panel as well as the mirror showing the water level.

Selection of the piping materials was in accordance with practice established during recent years, A.S.A. Standards and A.S.T.M. Specifications being applied throughout. A feature of the high-pressure steam piping is the carbon-molybdenum cast-steel header, Fig. 5, which in effect consists of a horizontal tee with a drain connection at the bottom and with the top connection welded to a vertical cast-steel leg that forms a secondary header for the piping to the boiler-feed-pump turbines. Before shipment it was subjected to a prolonged kerosene pressure test which was also applied with good results in the testing of high-pressure cast-steel valves.

Welding was used in a great majority of the piping joints and, with the exception of some low-pressure lines, the use of flanges was restricted to exceptional cases such as connections to feed pumps or to special valves. Split backing-rings were used only where service conditions were moderate. Since backing-rings involve a number of disadvantages when used in high-pressure, high-temperature lines, a joint without a separate ring was considered desirable. Preliminary examination of a joint of this type indicated that a new design should be developed especially for use in high-pressure piping. The "Westport" joint comprises a U-shaped groove for which an included angle of 55 deg was selected, with machined lips at the bottom of the groove. Fig. 4 represents a pipe-to-pipe joint and Figs. 6 and 7 show, respectively, an etched cross-section and a photograph of root bend specimens. The welding ends of forgings and castings are machined to an inside diameter corresponding to that of the lips on the pipe. After joining the lips at the root of the weld by oxyacetylene welding, the joint is completed by the usual electric-arc procedure including preheating and stress-relieving. Uniformly high ductility is obtained in the gas-welded bead which becomes an integral part of the weld. Field experiences confirmed the results of the development work with regard to excellent penetration at the root of the weld without "icicles" or unsound metal. Actually, the results were above expectations and use of the joint has been extended to intermediate-pressure piping, the design now being used in all piping with $^3/_8$-in. or heavier walls. Since a large part of the high-pressure piping is subject to the provisions of the Boiler Code, approval of the joint was necessary and was obtained after extensive tests and the usual process qualification procedure (3).

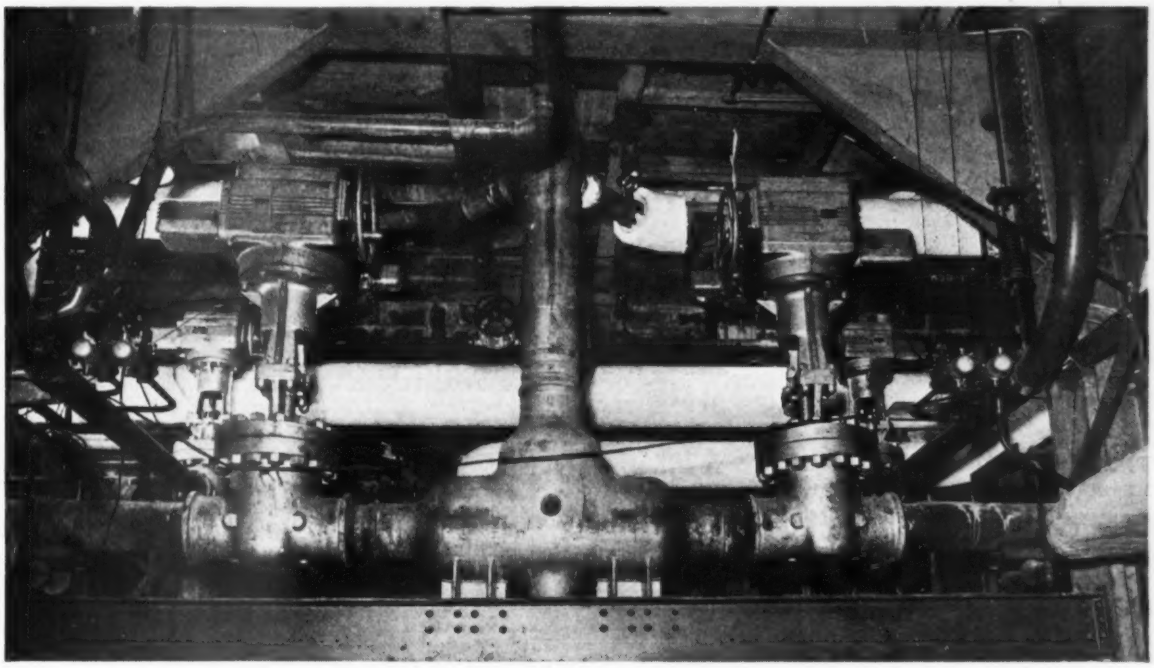

Fig. 5—Cast-steel high-pressure steam-header assembly

Operating Experiences

Development of system load made it impractical to adhere to original plans for a close inspection of the major equipment after a short period of service, and from the beginning the units have been in regular service. No difficulties except of a minor nature have been experienced and the equipment in general has gone through the initial period of operation with a minimum of trouble.

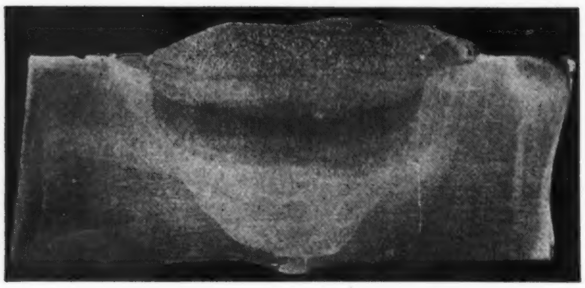

Fig. 6—Etched cross-section of "Westport" joint

The boilers were operated, using the reducing stations, before the turbine-generator was ready for service. Some minor troubles have been experienced with the burners resulting at times in unsatisfactory combustion. Leakage at economizer handhole plates was remedied by seal-welding in accordance with experiences elsewhere.

Fig. 7—Specimens showing ductility at root of weld

Following a short period of initial adjustment, the turbine-generator was up to speed continuously from August 25 to December 21, during which time it was taken off the line only twice for periods of about 45 min each to permit of operating the emergency governor. The operation of the unit has been quite satisfactory and the spring mounting of the generator core has fulfilled all expectations of quiet operation. At any point on the foundation, vibration and noise are at an exceptionally low level.

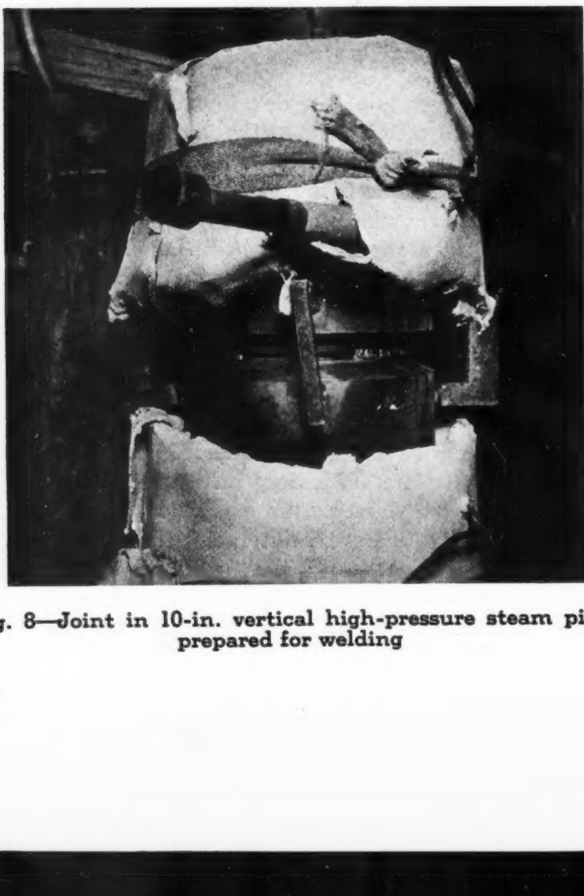

Fig. 8—Joint in 10-in. vertical high-pressure steam pipe, prepared for welding

The reducing stations have operated satisfactorily and without undue noise or vibrations at loads considerably in excess of their rated capacity.

The auxiliary equipment and control has been satisfactory with the exception of minor difficulties which have been overcome or are in the process of being corrected. None of these difficulties has been of a type to cause a shut down of major equipment.

Partial List of Equipment No. 1 Superposed Unit at Westport Station

Boilers
Two three-drum, bent-tube C-E type with water-cooled furnaces; 285,000 lb per hr evaporation with feedwater at 330 F; design pressure 1450 lb per sq in. in boiler drum.
Operating conditions—1325-lb, 915 F at superheater outlet.—*Combustion Engineering Company, Inc.*

Superheaters
"Elesco" type with two-pass elements; heating surface 8514 sq ft each.—*Combustion Engineering Company, Inc.*

Economizers
"Elesco" fin-tube continuous-loop type; heating surface 9600 sq ft each.—*Combustion Engineering Company, Inc.*

Air Preheaters
Ljungstrom regenerative type, one per boiler; heating surface 29,800 sq ft each.—*The Air Preheater Corporation.*

Pulverizers
Raymond bowl mills, size 483, two per boiler.—*Combustion Engineering Company, Inc.*

Ash Handling Equipment
Hopper and hydraulic sluice.—*Allen-Sherman-Hoff Company.*

Fans—Induced Draft
"Sirocco," size 11, one per boiler.—*American Blower Corporation.*
Drive—700 hp, three-phase, 440-volt, 720-rpm, wound-rotor motors.—*General Electric Company.*

Fans—Forced Draft
Type AHS, size 9; with inlet-vane control, one per boiler.—*American Blower Corporation.*
Drive—300 hp, three-phase, 440-volt, 1200-rpm, induction motors.—*General Electric Company.*

Precipitators
Cottrell electrostatic, one per boiler.—*Research Corporation.*

Fly-Ash Handling Equipment
Pneumatic type with dustless unloaders.—*United Conveyor Corporation.*

Turbine-Generator
14-stage, back-pressure turbine, double-shell, single-cylinder; design conditions 1250 lb per sq in., 900 F total steam temperature at the throttle, 205 lb per sq in. back-pressure.
25,000-kw, 0.8 power factor, 3600 rpm, 13,800-volt, three-phase, 60-cycle air-cooled generator with direct-connected exciter.—*General Electric Company.*

Boiler Feed Pumps
Two seven-stage, barrel-type with horizontally split inner-pump assembly, 1540 gpm at 330 F against a total head of 3985 ft.—*Byron Jackson Company.*
Drive—Two 2000-hp back-pressure turbines; 1250 lb per sq in., 900 F at the throttle, 205 lb per sq in. back pressure, 3600 rpm.—*Allis-Chalmers Manufacturing Company.*

Deaerating Feedwater Heater
One of 600,000 lb per hr, designed for 150 lb per sq in. Present operating conditions 90 lb per sq in., 330 F water temperature.—*Cochrane Corporation.*

Feedwater Storage Tank
Directly connected to deaerating heater. Designed for 150 lb per sq in.; capacity 146,000 lb.—*Cochrane Corporation.*

Piping
Fabrication and erection.—*W. K. Mitchell and Company, Inc.*

Valves
High-pressure, cast-steel valves.—*Crane Company.*
Non-return valves, 10-in. toggle-top, offset-type.—*Schutte & Koerting Company.*

Pressure Reducing and Desuperheating Stations
Two 330,000 lb per hr each.—*Republic Flow Meters Company.*

Control
Combustion control.—*Bailey Meter Company.*
Feedwater control.—*Bailey Meter Company.*
Reducing stations.—*Republic Flow Meters Company.*

Coal Conveyor
365 tons per hr capacity; five 36-in. belts in series.—*Robins Conveying Belt Company.*

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Furnace Temperature Measurements and Their Interpretation*

By H. KREISINGER, B. J. CROSS and E. H. KENNEDY

Combustion Engineering Company, Inc.

In comparing the exposed and the shielded aspirating type of thermocouple, as applied to measuring gas temperatures in pulverized coal furnaces, the advantages and limitations of each are discussed. While the latter permits more readings to be obtained without cleaning, the conclusion reached is that, with proper care, there is little difference in the results as between the two types. Calibration and testing couples for contamination are outlined and the construction of a water-cooled mounting described. Instructions for the use of both the shielded and the exposed couple are included.

THIS paper discusses the use of two types of thermocouples, namely the exposed type and the shielded aspirating type, for measuring temperatures in furnaces fired by pulverized coal.

By an exposed couple is meant a bare-wire couple completely exposed in the furnace. The hot junction of this couple is made of finer wire than the leads to reduce the radiation error, and to make the couple respond readily to temperature changes. The velocity at the hot junction is the normal velocity of the furnace gases which is of the order of about 50 ft per sec.

The shielded aspirating couple, which may be called the high-velocity couple, is enclosed by a refractory cylinder so that it cannot "see" either the flame or the boiler and furnace tubes. The hot junction is not reduced in diameter over that of the couple leads. In the type described in this paper the hot junction inside the shield is bare. Gases are drawn over this bare, hot junction at relatively high velocity of the order of about 150 ft per sec.

In both types of couples, platinum and platinum-rhodium wires are used as these are the only materials suitable for high gas temperatures. The lead wire of the exposed couple is 22 or 26 gage and the hot junction wire 30 gage. There is an extra supply of the lead wire at the cold end, arranged so that the wire can be pulled out at the hot end when the hot junction is replaced. The hot end of the exposed couple in its water-cooled mounting is shown in Fig. 1.

The hot end of the shielded couple is shown in Fig. 2. The entire couple, including the hot junction, is made of 26-gage wire. As in the exposed couple, the leads are of extra length for renewing the hot junction. The water-cooled mounting is somewhat larger in diameter to accommodate the extra tube through which gas is aspirated. The hot end of the mounting is arranged to support the porcelain tube which shields the hot junction of the couple.

Application to Pulverized-Coal Furnaces

In pulverized-coal furnaces the presence of ash dust and burning particles of coal in the furnace gases presents the greatest problem to temperature measurements. The average coal particle as it enters the furnace contains about 90 per cent combustible and 10 per cent ash.

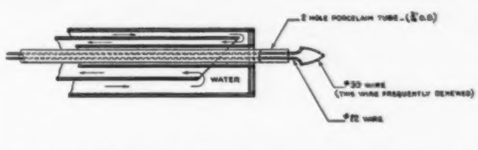


Fig. 1—Detail of fine-wire exposed couple

As the coal particles move through the furnace the combustible is burned off very rapidly at first, but as the free oxygen is used up, more slowly, until near the point where the gases leave the furnace, the particles contain only 1 per cent of the original 90 per cent combustible with 10 per cent ash. This proportion corresponds to about 10 per cent combustible in the flue dust. The process of combustion takes place at the surface of the particles and the heat generated by the combustion is also concentrated at the surface from which it is diffused into the surrounding gases. The particles are, therefore, always hotter than the gases. When these burning particles attach themselves to the hot junction they continue to burn until the combustible is all burned out. Part of the heat generated by this combustion is transferred to the hot junction and its temperature is elevated above that of the surrounding gases. Thus, layer after layer is deposited on the hot junction, the first layers from which the combustible has been burned out, insulating the burning layer that is being deposited on the hot junction and its temperature drops until almost constant temperature is reached. Whether this constant temperature is lower or higher

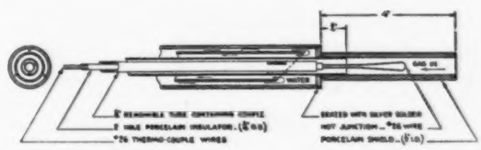


Fig. 2—Assembly at hot end of mounting for shielded couple

* A paper contributed by the Heat Transfer Division, Metropolitan Section, A.S.M.E., presented at New York, March 12, 1941.

than that of the surrounding gases depends on whether the hot junction loses or gains heat by radiation.

The rate at which the dust particles are deposited on the hot junction depends on the location of the couple in the furnace and on the nature of the coal ash. Generally, the nearer the location of the couple to the burner zone the higher is this rate of ash deposit. Also the rate of ash deposit is higher with some coals than with others.

With the shielded couple the rate of ash deposit on the hot junction is much lower than with the exposed couple. Therefore, the shielded couple can be used over longer periods of time without cleaning, and the temperature traverse across a section of stream of gas can be made in much less time. This is the principal advantage of the shielded couple.

Use of Exposed Couple

In the exposed type of couple the ash deposit forms on the upstream side of the wire in the shape of a ribbon, the downstream side remaining nearly clean. This growing ash deposit reduces the heat input to the hot junction and the couple indicates lowering temperature which can be taken as a measure of the rate at which the ash is deposited on the wire and which can also be used to determine the frequency of cleaning. Usually the rate and effect of fouling are such that three temperature readings may be taken between cleaning periods without causing serious error. In such cases the readings are overlapped so that the effect of fouling is continually checked. For example, points 1, 2 and 3 are read at the first insertion, 3, 4 and 5 at the second and 5, 6 and 7 at the third, etc.,

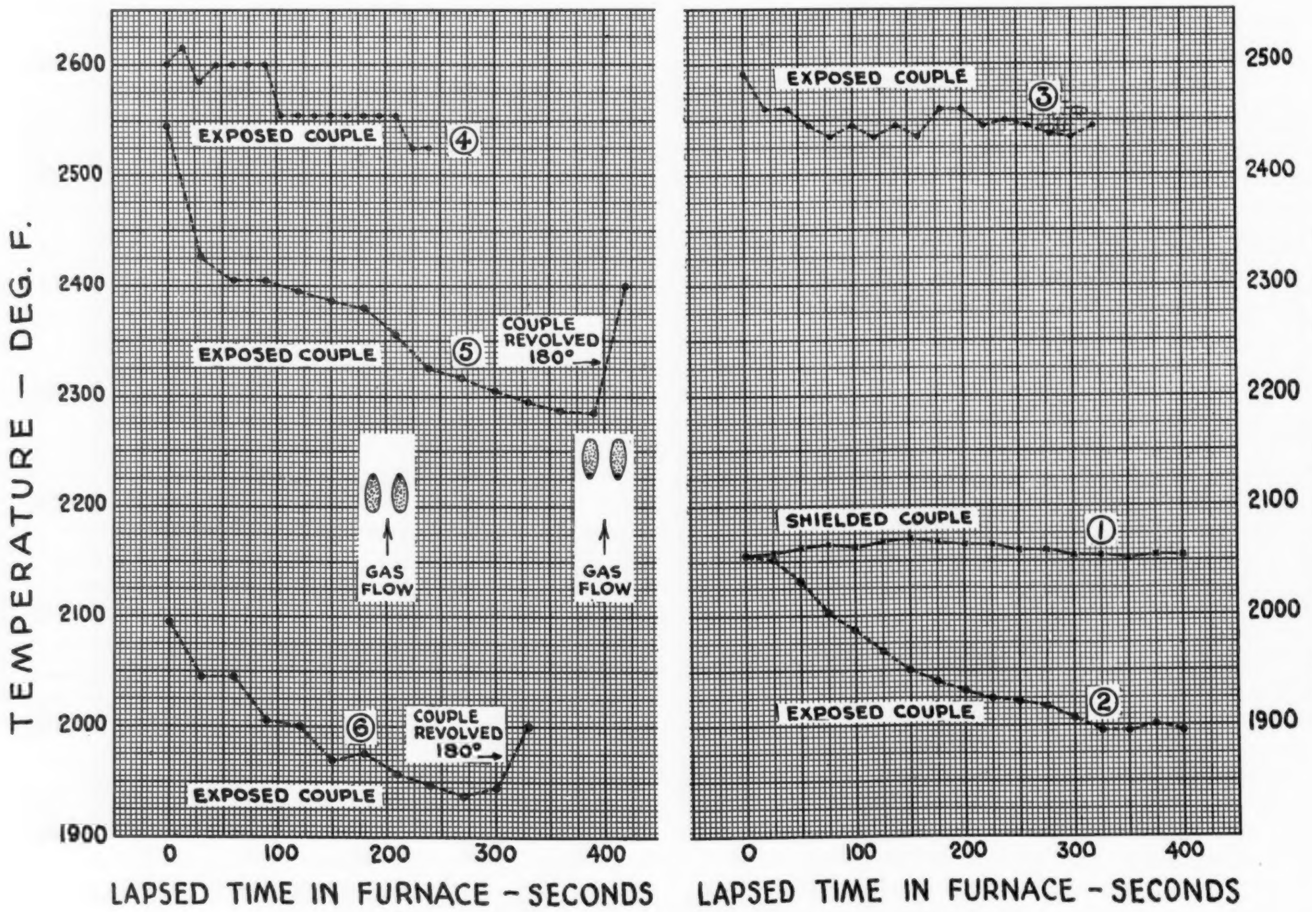


Fig. 3—Variations in indicated temperature at one point in furnace

The shielded aspirating couple with its high-velocity flow of gases collects ash at a much lower rate than the exposed couple. This is somewhat different from the sticking of slag on boiler tubes and superheater elements. Experience shows that the faster the gases flow through the boiler and superheater the more slag or ash accumulates on their surfaces. The average velocity of gases and dust particles passing through the superheater is about 75 ft per sec. It is probable that the way in which the gases and the dust flow over the hot junction wire has a marked effect on the deposition of ash. In the shielded aspirating couple the gases and the dust flow mostly parallel to the wire, whereas in the plain exposed couple they flow across the wire, and the dust sticks more when it strikes the wire at right angles.

the couple being cleaned between insertions. Three readings may be made in less than ten seconds. Speed is essential.

Use of Shielded Couple

With the shielded couple the ash is deposited mostly on the short cross piece of the wire where the hot junction is located, but the rate of deposit is much lower and the couple needs to be cleaned at much longer periods than is the case with the exposed couple. With the shielded couple an entire traverse of ten or twelve points may be made with one insertion. It responds very quickly to changes in temperature and a reading may be made in three to five seconds. After a reading is made the aspirator is shut off and the couple moved to a new posi-

tion. Even with the aspirator on continuously there is but little change in the indicated reading over a period of a minute, which is the usual time required for a traverse. For this reason traverses with a shielded couple may be made more deliberately than with the exposed couple. Speed in furnace temperature measurements is important because it makes all readings in a traverse more nearly simultaneous.

The annoying feature is the frequency of failure of the porcelain shields. Experiments with other materials are being tried and it is hoped a more satisfactory shield can be developed.

Comparison of Readings Obtained with Exposed and Shielded Couples

Curve 2, Fig. 3, shows how the temperature at one point in a gas stream at the exit from the furnace indicated by an exposed couple varies when taken over a period of 400 sec. Curve 1 shows the temperature at the same point as indicated by a shielded couple. The shielded couple indicates very little change in temperature, whereas the exposed couple indicates a drop of 150 deg. F. Curves 5 and 6 are similar in shape to Curve 2 and show a rapid decrease in indicated temperature during the first few seconds of exposure.

When the exposed couple is used to measure gas temperatures near the fusion point of the coal ash, the drop in indicated temperature over the same period seems to be less. This characteristic is shown in Curves 3 and 4, Fig. 3.

Under most conditions, an exposed couple collects ash quickly on the sides of the exposed wires facing the direction from which the gas comes. If the couple is revolved 180 deg after this dust collection occurs, the indicated gas temperature rises considerably. The amount of this rise is shown graphically in Curves 5 and 6, Fig. 3. The small illustrations between Curves 5 and 6 indicate the deposit of ash on the wire with respect to flow of gases before and after turning the couple.

It is seldom that the temperature at a single point in the furnace or boiler passes is of much value. It is necessary to obtain the temperature at a number of points in the same section of gas stream in order to calculate the average temperature at this section.

Curves 7, 8, 9, 10 and 11 of Fig. 4 show graphically some typical gas temperature traverses taken through two different openings in the furnace. Three different procedures are represented.

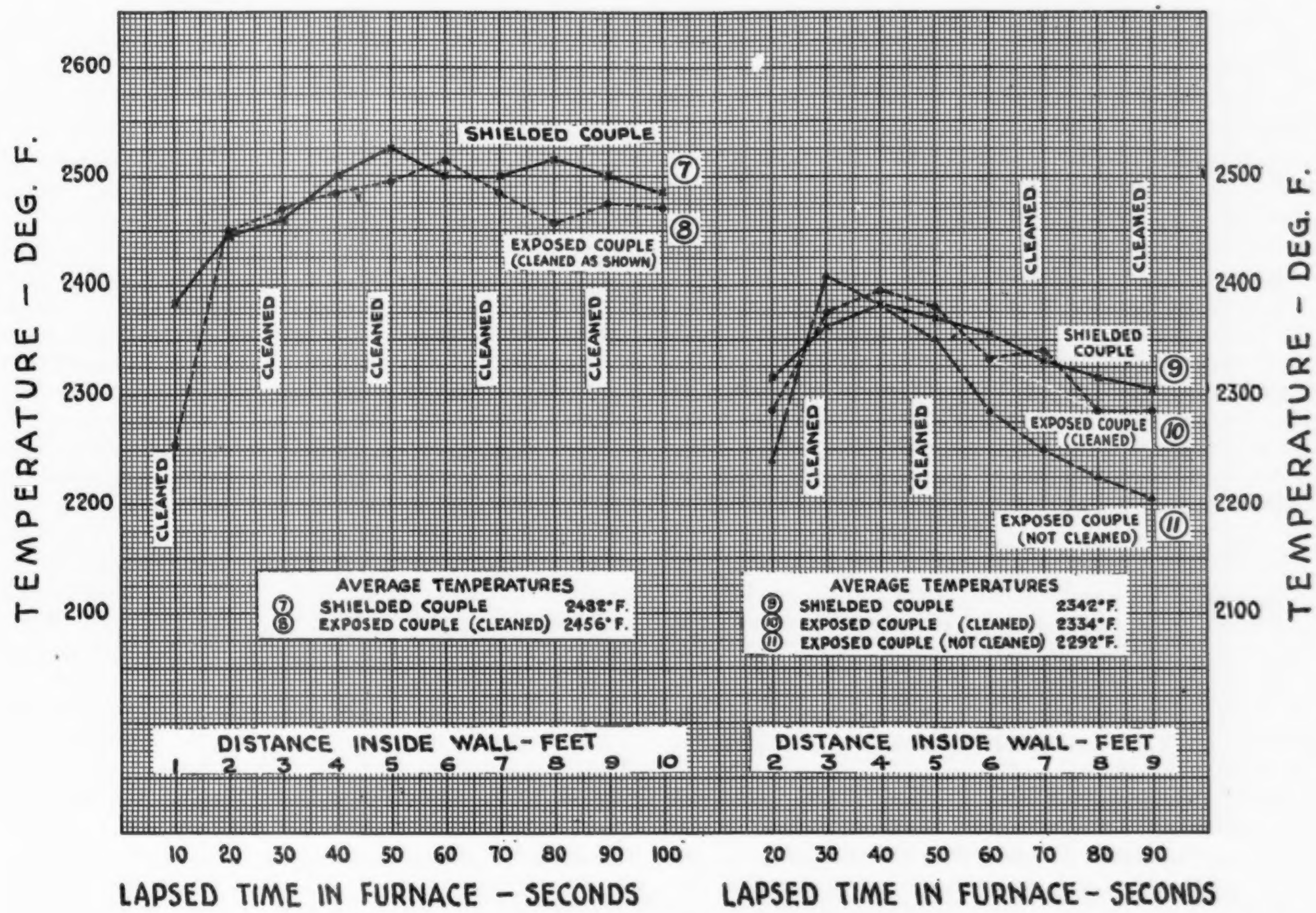


Fig. 4—Traverse variations across furnace

Curve 7 gives the temperature readings obtained with the shielded couple which has not been cleaned during the traverse. Curve 8 gives the temperature obtained with the exposed couple which was cleaned four times during the traverse as indicated in the figure. Curve 9 shows the temperature at eight points obtained by the shielded couple which has not been cleaned during the traverse. Curve 10 gives the temperatures at the same points as indicated by the exposed couple cleaned four times as shown in the figure, and Curve 11 shows the temperature indicated by an exposed couple not cleaned during the traverse.

The average temperature, in one case, as indicated by the shielded couple, is 2482 F, as shown by Curve 7. The average temperature indicated by the exposed couple taken through the same furnace opening and cleaned every other reading is 2456 F as shown by Curve 8. Here the difference in the average indicated temperatures is only 26 deg F.

In another case the shielded couple (Curve 9) indicates an average temperature of 2342 F, the exposed couple cleaned every other reading (Curve 10) indicates 2334 F, and the exposed couple not cleaned during the traverse (Curve 11) indicates 2292 F. Here the difference in the average indicated temperatures of the shielded couple and the exposed couple cleaned is only 8 deg, while between the shielded couple and the exposed couple not cleaned the difference is 50 deg F.

Indication of True Temperature Questionable

It is a question if the temperature indicated by either couple represents the true temperature of the gas. In fact, it is doubtful if there is such a thing as "true temperature" in a gas containing burning particles in suspension with continuous flow of heat from these particles to the gas. For the purposes that most gas temperature measurements are made, consistent temperatures with reasonable accuracy that can be obtained at a large number of points in a short time are as valuable as highly accurate temperatures at fewer points in a longer time. The most useful temperature measurements are those taken at the sections of gas streams entering the boiler and superheater, and leaving the superheater. Such measurements are made to determine performance of the superheater, which is very important in the design of high-pressure and high-temperature steam generating units. As far as results are concerned, there is little difference between the two couples. With proper care in operation, almost identical temperatures are obtained.

Recalibration and Testing of Couples for Contamination

All couples are susceptible to contamination and consequent change in calibration. This is true of platinum as well as base-metal couples. Platinum alloys with most of the metallic elements but is resistant to the oxides. It should, therefore, not be exposed to reducing atmospheres. Carbon monoxide particularly appears to "poison" platinum.

Most of the measurements of furnace gas temperatures are made near the furnace outlet where the atmosphere is practically neutral. In the pulverized-coal furnace, the gases contain a large quantity of finely divided ash particles of various composition and also particles of unburned carbon. These ash and carbon particles lodge on the thermocouple wire where the carbon may burn. This may result in minute points of high temperature and possibly small areas where conditions are reducing. Whatever the mechanism, it is a fact that platinum wire exposed in a furnace becomes contaminated and its thermoelectric properties undergo a change. This is true even when they are protected in refractory sheaths although the rate of change may be reduced.

Couples used in furnace temperature measurements are almost without exception used in water-cooled mountings. The portion of the leads within the mounting are protected from contamination because they are maintained at low temperature. We need only be concerned with the exposed hot junction. This amounts to not more than $1^1/_2$ in. of couple.

Tests for contamination of a thermocouple may be made by connecting it to a sensitive galvanometer and clamping the hot junction to a water-cooled tube so that its temperature will remain constant. The leads are then heated near the hot junction by means of a small hot flame. Deflection of the galvanometer indicates inhomogeneity and if the galvanometer is calibrated, the degree of contamination may be estimated. Both the platinum and the alloy wire should be thus investigated. Usually the deflections are both positive and negative and to some extent compensating.

Another method of testing for inhomogeneity is to sever the couple at the hot end and to weld on a length of new wire to each lead, a piece of new platinum is welded to the old platinum lead and a piece of new alloy wire to the platinum-rhodium lead. Each lead is then tested separately in a manner similar to the test, previously described.

It has been observed that on prolonged exposure to moderate temperatures, under 1000 F, the platinum-rhodium wire changes in color and acquires a bluish sheen. This is believed due to a migration of some of the rhodium to the surface of the wire. It does not seem to affect the calibration of the wire and the color is restored by heating to about 1000 F and quenching. In one instance where a number of couples were used to measure boiler-tube temperatures, the couples were necessarily left in place until a convenient outage of the boiler permitted their removal. The leads of these couples were badly discolored. A calibration, however, proved that their thermoelectric properties were not appreciably altered.

There is no practical method for correcting the readings of a couple for inhomogeneities later determined. The only thing to do is to discard the couple when it is discovered to be contaminated. Fortunately this does not mean that the entire couple has to be sacrificed. As only the exposed part is affected, this can be removed and a new junction made at the unaffected part of the wire. The part that is scrapped can be salvaged at about 60 per cent value of the new wire.

If contamination of a couple is suspected after use and if it is desired to make corrections to the later readings of the couple, it should be recalibrated under as near as possible to the actual conditions of use. It should be mounted in a water-cooled tube with the same amount of exposed wire and insulation. There is, however, always the question as to when the contamination occurred and what readings are affected. If the recheck shows any considerable change in calibration, all of the readings may be questioned. It is better to determine just how long it is safe to use a couple and then renew the hot junction frequently enough so that corrections are not required. It has been our practice to change the No. 30 wire after three or four traverses depending somewhat on the temperatures to which it has been exposed and to the character of the ash. The heavier wire used in the shielded couple should be renewed at least after each day of use: more often if conditions are severe.

A typical study for contamination of a used couple indicated parasitic couples in the platinum wire giving values as high as 35 deg F when heated to about 2500 F. On the platinum-rhodium wire, the effect of contamina-

tion was much less and the maximum couple showed values equivalent to only 2 deg F. That these parasitic couples were largely self-compensating is proved by the fact that the couple, recalibrated under conditions of its actual use, showed a maximum deviation of 7 deg F.

Construction of Water-Cooled Mounting

Figs. 1, 2 and 5 show how the water-cooled couple mounting is constructed. The "cold" end is a brass head counterbored to receive the brass tubing which forms by concentric arrangement the outside of the mounting

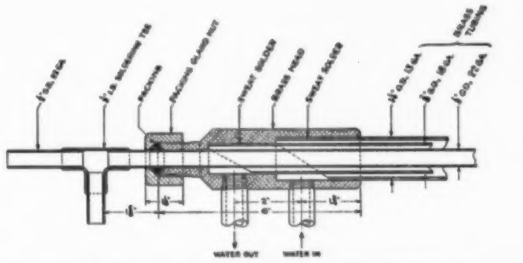


Fig. 5—Assembly at cold end of mounting for shielded couple

and the annular passages for water and gas. Holes for $^1/_2$-in. brass nipples are drilled and tapped at the proper points for inlet and outlet cooling water. A feature of this brass head is the packing gland which allows the inside tubing to contract and expand with changes in temperature without putting a strain on the tubing. The brass tubing is fastened to the brass head by sweat-soldering with ordinary solder. The opening at the "hot" end of the mounting is closed by brazing in a small brass plug properly fitted. The porcelain insulators carrying the thermocouple wires are supported and pro-

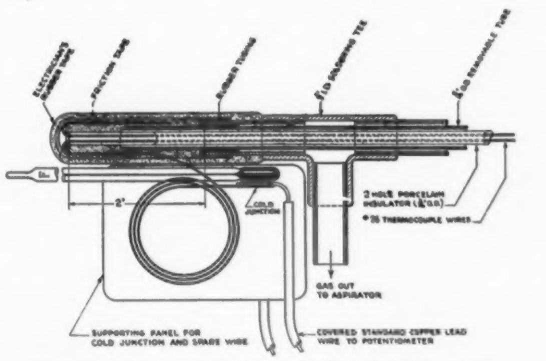


Fig. 6—Details of $^1/_2$-in. I.D. soldering tee

tected by a $^5/_{16}$-in. tube placed in the center of the mounting. A study of the hot end of the mounting will show the relation of the hot junction, insulators and radiation shield to each other. Fig. 6 is a more detailed sketch of the "cold end" showing the method of bringing out the thermocouple wires and of making it air tight.

Fig. 1 shows how the "hot end" of the exposed couple is constructed. The hot junction is made of No. 30 wire welded to leads of No. 22 or No. 26 wire. The water-cooled mounting for an exposed couple is essentially the same as for the shielded couple except that it has one less concentric tube. Two small brass tubes are provided in the exposed couple mounting: one for carrying the thermocouple wires and insulators and the other for drawing a gas sample for Orsat analysis.

The wires forming the hot junction may be welded together by a small electric carbon arc welder either before or after the wires are placed in the mounting. A diagram of the arc welder is shown in Fig. 7.

The aspirator, used to draw gas over the hot junction is shown in Fig. 8. This is connected to the mounting by a piece of rubber tubing.

Operation of the Shielded Couple

Before using the shielded couple to make a gas temperature measurement, the operator should determine for himself the minimum amount of gas which must be drawn over the hot junction to give the maximum indicated temperature. To make this determination, the cooling water is turned on and the couple is placed in the gas stream when the gas temperature is to be determined.

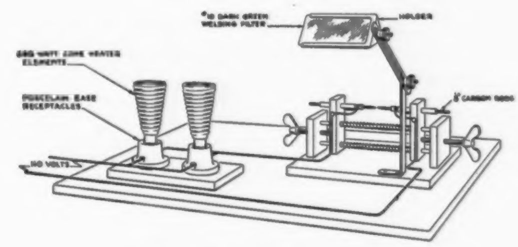


Fig. 7—Sketch of arc welder

Then the compressed air valve to the aspirator is opened enough to produce a small flow of gas over the hot junction. It will take about a minute for the radiation shield to become heated. Then the aspirator valve is opened up slowly until the reading on the potentiometer becomes about constant. If additional gas drawn over the hot junction does not increase this reading, this will have been the minimum velocity over the hot junction which must be maintained to give the correct reading of temperatures taken at this point.

A higher velocity than the minimum is used to insure a sufficient quantity of gas being drawn over the hot junction at all times because the flow of gas can be affected by:

(1) A change in compressed air pressure to the aspirator or,
(2) A change in the resistance of the annular gas passage in the mounting. This passage may gradually become clogged up or restricted by dust and moisture from the hot gas.

A rough measure of the quantity of gas being drawn over the hot junction can be obtained by inserting a

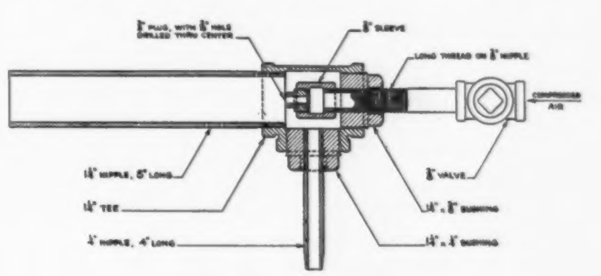


Fig. 8—Detail of aspirator

small orifice, in some place in the line between the aspirator and the thermocouple mounting. An aspirator

similar to the one shown indicated a maximum velocity through the $^1/_2$-in I.D. radiation shield of 135 ft per sec at 2000 F using compressed air at about 80 lb per sq in. pressure.

Precautions to Be Observed in the Use of the Shielded Couples

1. The user of water-cooled mountings should make it a rule to turn on the cooling water as soon as the inlet and outlet water hoses are connected.

2. The user should make sure that annular gas space is clean and free from obstruction before the mounting is used for a temperature measurement. Moisture from the hot gases will condense on the cooled surfaces of the gas passage, and cause the dust in the gas to stick to them. After an all-day use of the couple the dust in the gas passage should be loosened with a wire near the "hot" end of the mounting and then flushed out with water. Otherwise, the dust paste will dry and harden and the acid in the condensed vapors will corrode the brass tubing if the mounting is not cleaned.

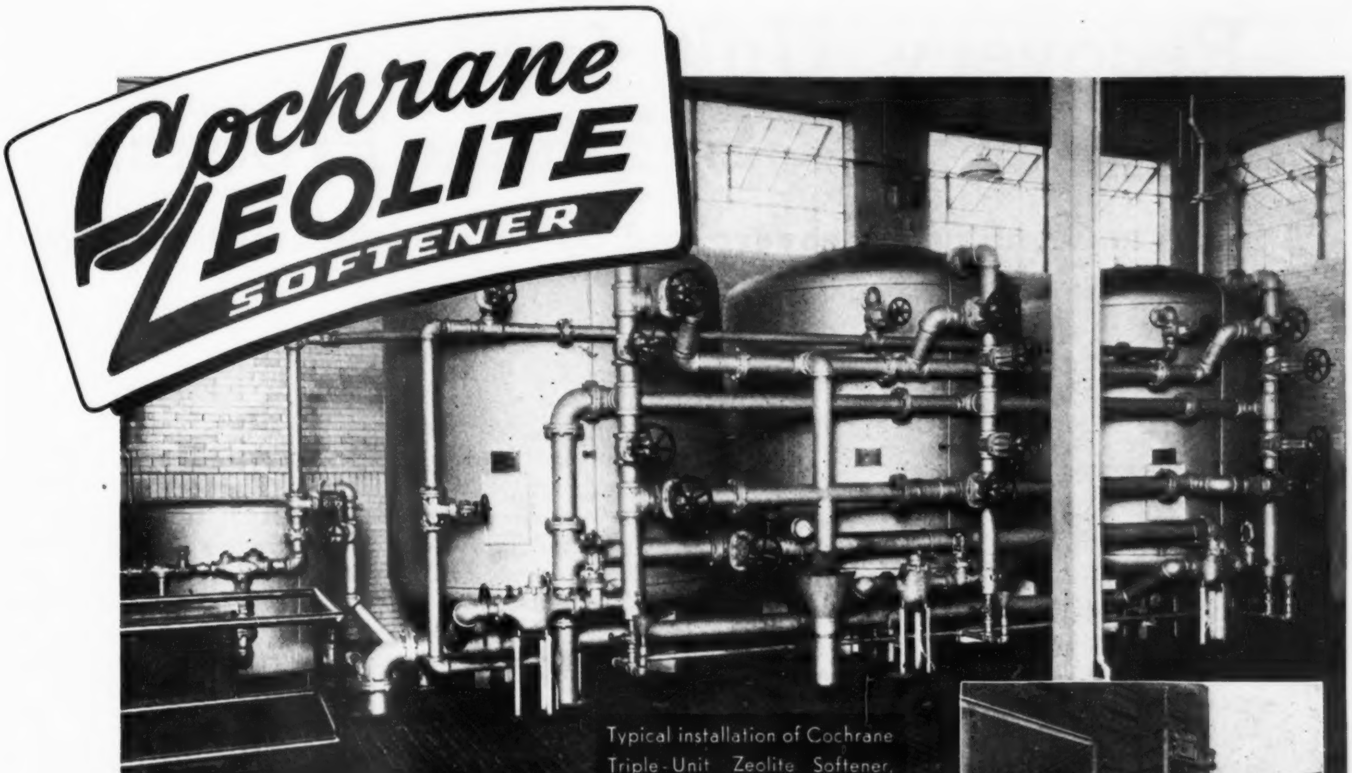
3. The radiation shield should be removed and the hot junction cleaned with a piece of fine emery paper before a gas temperature measurement is made. Thereafter, the hot junction of the couple should be inspected and cleaned if necessary after each traverse. This practice will usually allow about two minutes for taking a complete 20-point temperature traverse—10 in and 10 out—reading the temperature at one-foot intervals. A small deposit of ash will form on the tip of the hot junction facing the open end of the radiation shield. For this reason it is recommended that if gas samples are to be drawn for gas analysis the temperature traverse be completed before any gas samples are taken.

4. After the mounting has been inserted the aspirator should be turned on and the radiation shield allowed to heat up for a minute before taking the first temperature reading.

5. The shielded couple mounting, constructed as described, is suitable for measuring gas temperatures up to nearly 2600 F. At or above that temperature, the hot end of the $^1/_2$-in. and $^5/_{16}$-in. brass tubing will become too hot and melt.

6. Reference to the frequent breaking of the porcelain radiation shields has already been briefly made. Little breakage occurs when they are used in gases below 2200 F, but when used in gases at 2500 F a single traverse is about all that can be obtained with one shield and sometimes the shield breaks before the traverse is completed. This breaking of the porcelain shield near the brass mounting is caused by contraction and expansion strains. It has been suggested that the end of the porcelain shield next to the mounting be wrapped with stainless steel screen wire and covered with alundum cement for reinforcement and protection.

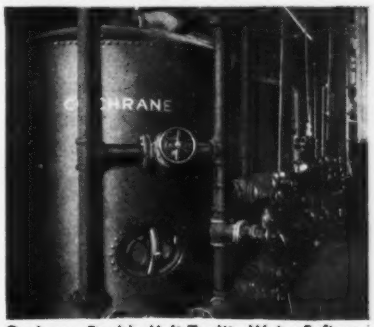
7. A minimum water pressure of 65 lb per sq in. for water cooling is required for a mounting 12 ft long when it is used for measuring gas temperatures up to 2600 F. If two mountings are to be used simultaneously on one supply line, higher water pressure than that mentioned is required.



Typical installation of Cochrane Triple-Unit Zeolite Softener.

Cochrane Double Unit Zeolite Softener at an Oil Refinery.

Cochrane Double Unit Zeolite Softener in a Technical Institution.



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Recovery Unit for Sulphate Process

Applied to Chemical Recovery and By-Product Steam Production

By F. H. ROSENCRANTS, Vice Pres.

Combustion Engineering Company, Inc.

The primary objective of the recovery unit, as employed with the sulphate process in the pulp and paper industry, is high reduction and recovery of chemicals from the spent liquor used in the digesters, accompanied by continuous reliable production; and the secondary purpose is the generation of by-product steam. The liquor originally contains between 40 and 50 per cent solids, or about 65 per cent by weight after being concentrated in the cascade evaporator where it is exposed to the hot boiler outlet gases. These solids have a heat value of about 7000 Btu per lb and an ash content of approximately 50 per cent, the liquor being burned in the furnace and the chemicals recovered by treating the ash residue. From 10,000 to 12,000 lb of steam is produced per ton of pulp. The low fusing temperature of the ash and the high moisture content of the liquor offer problems in design and operation. These are discussed in the following excerpts from a paper presented at the Annual Meeting of the Technical Association of the Pulp and Paper Industry, New York, February 17–20, 1941.

TWO important obstacles encountered in the attainment of continuous reliable production with a chemical recovery unit have their origin in the high percentage of low-fusion temperature ash and in the high moisture content of the fuel at admission to the furnace. Fused ash tends to plug the gas passages and excess moisture may put out the fire. The fusion temperature of the ash carried in suspension in the combustion gases is of the order of 1400 to 1500 F, and unless cooled below 1300 F it has a tendency to stick to everything with which it comes in contact.

In practical design the gas temperature does not fall below 1300 F until it has passed over a considerable amount of boiler and superheater surface, and in this zone slag adherence must be expected. It may, however, be reduced to a minimum and its character rendered less objectionable by employing vertical tubes spaced on wide centers and arranged for a gas flow parallel thereto. These provisions result in a minimum contact of suspended solids with the tube surface, a weak porous slag structure and the absence of supporting surfaces on which solid particles can deposit and accumulate. Provision should be made for adequate hand lancing.

The boiler or superheater surface (see Fig. 1) with which the first thin layer of liquid or sticky slag particles come in contact is not at a temperature of more than 800 F; hence they are quickly cooled to a point well below the sticky condition, and they become particles of dry dust having little adhesive strength to the tube and also little cohesive strength to the immediate subse-

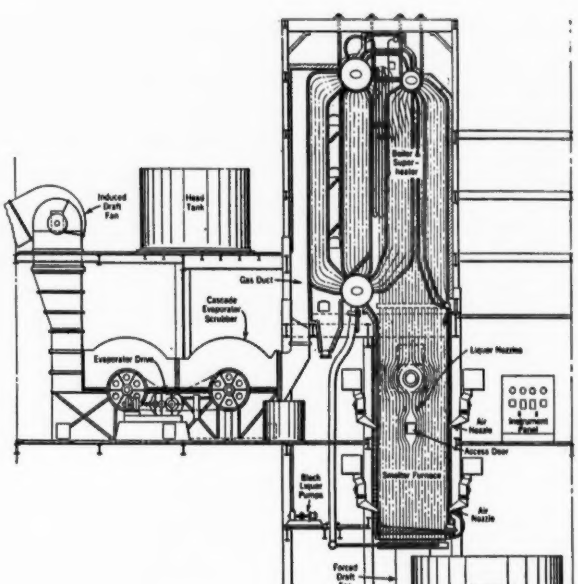


Fig. 1—Typical design employed with several units now in operation

The cascade evaporator, into which the spent liquor from the digesters is pumped, consists of a tank containing a series of circular plates or disks which rotate, the level of the liquor being just below the rotor shafts. Hot gases from the boiler outlet pass over the disks, the surfaces of which are wetted by the liquor, and evaporation takes place to a point where the solids become about 65 per cent by weight of the solution. From the evaporator the liquor is further heated and pumped to the nozzles in the furnace where it is burned, producing by-product steam. The ash from the bottom of the furnace is dissolved and treated for the recovery of chemicals.

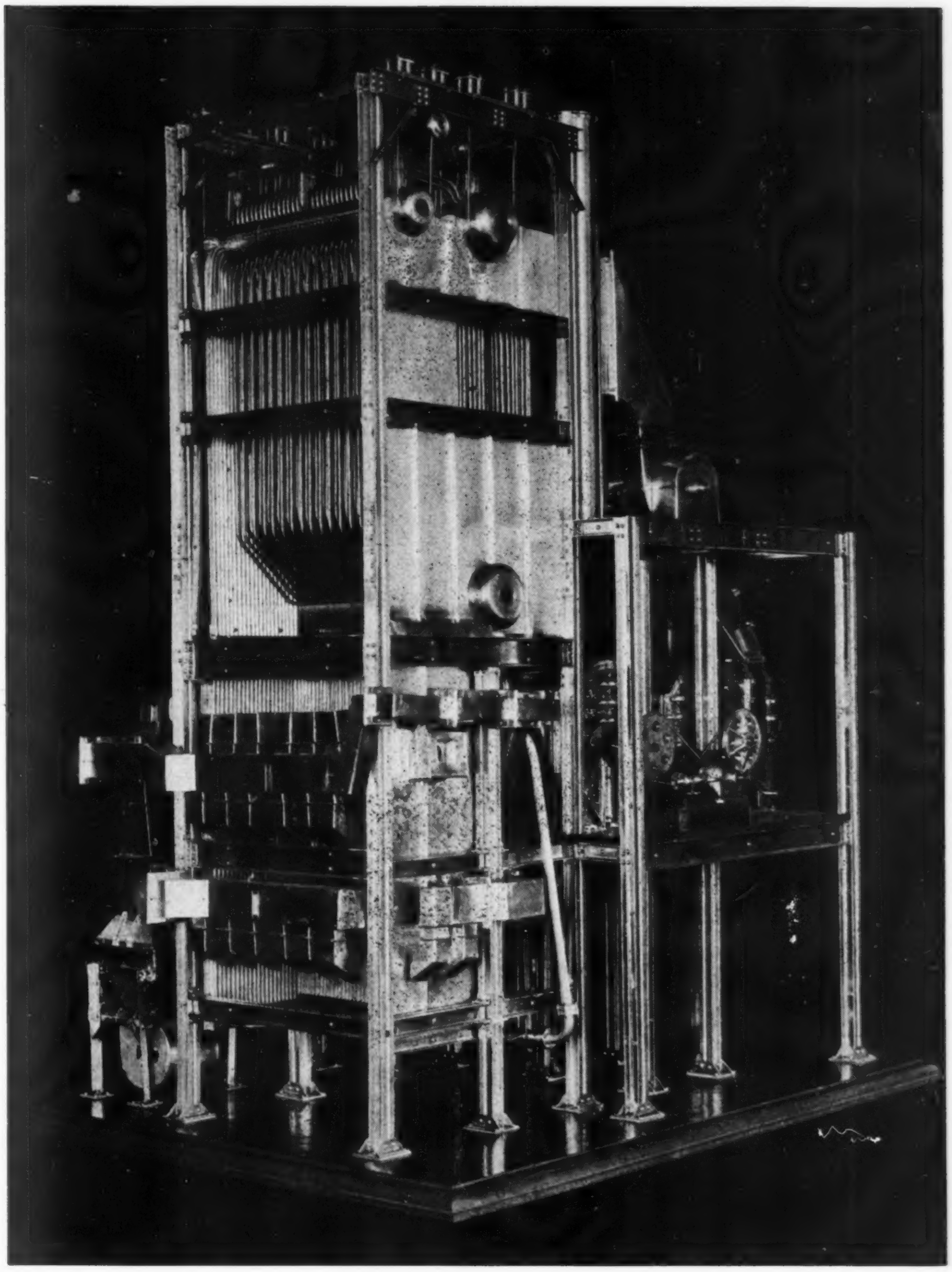


Fig. 2—Model of C-E recovery unit

This scale model, constructed of aluminum by E. C. Keithley, service engineer of Combustion Engineering Company, was exhibited at the recent Annual Meeting of the Technical Association of the Pulp and Paper Industry.

quent layer. However, each successive layer will cool more slowly, due to the accumulative insulating influence, until finally they do not have sufficient time to cool below the sticky point before subsequent particles deposit. At this point the coating starts forming until ultimately a hard vitreous accumulation results.

Gas flow parallel to the tubes contributes to a slower rate of contact and thus extends the period of cooling between deposits of successive layers. This results in a thicker layer of dust and highly porous slag, and makes removal of the deposit much easier and less frequent.

In the temperature zone above 1700 F slag forms on the heating surfaces in a relatively thin layer. The insulating value of the initial deposits retards the cooling influence of the tube beneath to the point where the heating influence of the gas maintains the surface at a temperature above the melting point and causes the surface slag to run and drip. Above 1800 F this action results in a self-perpetuating layer of slag $^1/_8$ to $^3/_8$ in. thick, as indicated in Fig. 3.

Spacing the boiler and superheater tubes on wide centers minimizes the obstructive influence to gas flow, facilitates lancing and provides greater clearance for the free fall of dislodged material. The tubes ahead of the superheater are spaced on 12-in. centers and $10^1/_4$ in. from front to rear. Those of the superheater are on 6-in. centers across and $5^1/_8$ in. front to rear. A small front upper drum is provided to avoid horizontal runs which would otherwise be necessary to connect the boiler tubes ahead of the superheater into the main steam drum. The lower sloping and horizontal elements of these tubes are unavoidable.

The front furnace wall fin tubes are spaced on $5^1/_2$-in. centers and the spacing of tubes in the boiler passes beyond the superheater conforms to normal boiler practice. Material which deposits on this surface is in the form of a dry dust which is readily removed by mechanical soot blowers. Deposited material in the hopper below the rear passes is continuously removed and returned to the system via the cascade evaporator.

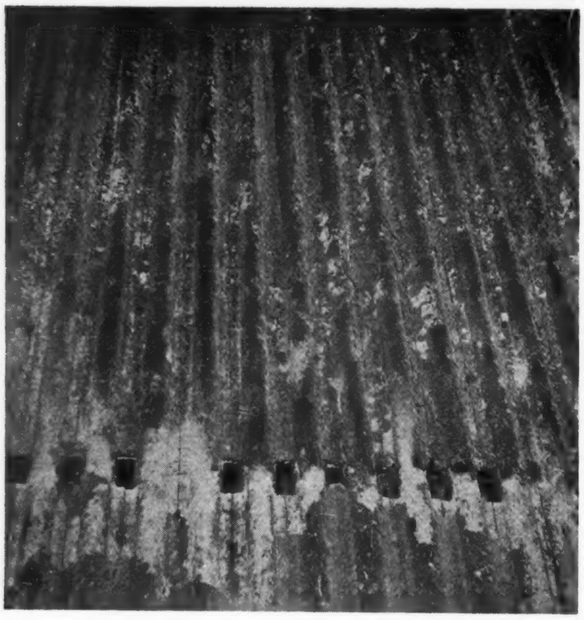


Fig. 3—Furnace wall surface after six months continuous service, showing character of coating perpetually maintained

A pump circulates and sprays a solution of weak liquor or water and ash into the hoppers, sweeping out the ash deposit and delivering it to the dissolving tank.

The baffle immediately behind the superheater is formed by putting fins on the boiler tubes and sealing the space between the fins with short sections of 1-in. T-bars welded to the fins.

Fig. 4 represents the temperatures throughout the vertical pass of the boiler and superheater as established by thermocouple measurements during full-load operation.

Moisture Problems

The liquor fed to the furnace is a mixture of inert chemicals, and organic solid matter, made up of the intercellular structure of the wood, and water. The organic matter, from which all of the heat of the liquor is derived, makes up from 50 to 60 per cent of the total solids and has a heat value ranging from 6000 to 7200 Btu per lb. The ratio of organic matter to inert chemicals in the liquor is influenced by the character of the product being produced, by the kind of wood used, and to some extent by the routine established in the specific mill. A paperboard mill using pine produces a liquor high in organic matter; one producing high-bleach pulp has liquor low in organic matter; and jack pine produces a higher heat-value liquor than either chestnut or gum wood.

The importance of moisture control in the liquor to the furnace is obvious and stable operation demands that it be held within narrow limits. At some upper limit it puts out the fire. With a high heat value of solids this point might be 50 per cent and with a low heat value 40 per cent. Furnace conditions steadily improve with increase in the solid content; carryover of solids with the products of combustion is reduced; and it is believed that there is also some improvement in chemical reduction. Furthermore, steam production improves almost pound for pound with the reduction of the amount of water sprayed into the furnace.

To obtain the maximum fluidity and promote flow to the suction of the liquor pump, the liquor is heated by direct contact steam to a little over 200 F. A second heater raises the temperature to a predetermined level on the discharge side of the pump.

Introduction of Liquor Into Furnace

Liquor is delivered to the furnace through two nozzles at each end, directed along the axis parallel to the side walls. To obtain an even distribution over the whole cross-section of the furnace the nozzles are preferably given a slow rocking motion in a vertical plane. Owing to the elevated temperature of the liquor above the boiling point at atmospheric pressure, a part of the contained moisture flashes into steam at release from the nozzle and expands each particle of liquor to several times its normal diameter with a corresponding increase in surface (i. e., as the square of the diameter). It is to this process of increasing the exposed surface that the drying operation in suspension owes its success. The temperature to which the liquor is elevated before spraying is most important.

A supply of secondary air, sufficient for developing the maximum heat in the drying zone, is admitted at a point below the spray nozzles. Also, to insure complete combustion and a maximum consequent steam production, a tertiary air supply in an amount exceeding the theoretical requirements is admitted at high velocity at a point well above the sprays. A belt of air ports near the furnace bottom provides the restricted air supply essential to the reduction process.

Reduction

Sodium sulphide (Na_2S) is a combustible material. In the combustion process it takes on oxygen to form

Fig. 4—Thermocouple temperature survey at full capacity after several months continuous operation

sodium sulphate (Na_2SO_4) just as carbon (C) takes on oxygen to form carbon monoxide (CO) or carbon dioxide (CO_2). If, however, sodium sulphide, carbon and a limited amount of oxygen are intimately mixed and subjected to sufficient temperature, the carbon will claim its full requirement before any oxygen is available for the sodium sulphide. The stronger affinity of the carbon for oxygen is such that if sodium sulphate (Na_2SO_4) is intimately mixed with carbon and the mixture raised to the required temperature the carbon will rob the sulphate of its oxygen and reduce it to sulphide. This condition is deliberately created in the bottom of the smelter furnace. Only a limited amount of air is admitted at this point, enough to augment the oxygen supplied by the sodium sulphate present to the point required to transform all the carbon to carbon monoxide and partially to carbon dioxide but so restricted as to be sure of no excess which would permit retention of oxygen by the sodium sulphate. Correctly designed equipment, skillfully operated, is capable of reducing as much as 98 per cent of the sulphur supplied to the furnace as a sulphate to sulphide. Normally 92 to 96 per cent reduction is obtained.

Stack loss of chemical with all types of furnaces is substantial and amounts to at least 100 lb per ton of pulp. It can be effectively recovered, however, by mechanical and scrubbing means, and electric precipitation has also proved effective.

Steam Production

The by-product steam production is indicated by the typical heat balance shown in the accompanying table.

TYPICAL HEAT BALANCE

Pressures and Temperature Conditions			
Design pressure, pounds			475
Safety valve setting, pounds			470
Operating steam pressure, lb			450
Total steam temperature, deg F			700
Feedwater temperature, deg F			320
Air temperature to furnace, deg F			300
Liquor temperature to unit, deg F			190
Liquor Solids			
Approximate analysis, %			
Carbon			39.5
Hydrogen			3.5
Oxygen plus nitrogen			11.5
Sulphur			3.5
Ash			42.0
Heat value, Btu/lb			7000
Design Data			
Dry solids per ton of pulp (before salt cake addition), lb			3000
Excess air at cascade evaporator outlet, %			30
Salt cake added per ton, lb			200
Heat datum base, deg F			32
Gas temperature to cascade evaporator, deg F	450	600	700
Gas temperature out of cascade evaporator, deg F	230	260	290
Solids in liquor to cascade evaporator, %	54.2	46.7	43.1
Temperature of liquor from cascade evaporator, deg F	180	185	190
Heat Input, M-Btu			
1 Heat in dry solids	21000	21000	21000
2 Sensible heat in liquor	590	730	810
3 Heat in steam to liquor heater	174	157	140
4 Heat in steam to air heater	864	864	864
5 Heat in air to steam heater	210	210	210
6 Total input	22838	22961	23024
Heat Distribution, M-Btu			
7 Dry gas loss	1050	1206	1361
8 Water vapor loss	4230	5290	5940
9 Reduction of added salt cake	600	600	600
10 Reduction of salt cake formed from sulphur	1400	1400	1400
11 Heat of fusion and sensible heat in smelt	1420	1420	1420
12 Heat in condensate from air heater	342	342	342
13 Heat loss in soot blowing (1.0%)	228	229	230
14 Radiation and unaccounted for (2.0%)	457	459	460
15 Heat in blowdown (0.5%)	114	115	115
16 Net heat available for steam	12997	11900	11156
17 Total distribution	22838	22961	23024
Steam Production, Lb			
18 Per ton of pulp	12100	11100	10400
19 Per ton of pulp from and at 212 deg F	13400	12280	11500
20 Per lb of dry solids from and at 212 deg F	4.47	4.09	3.83

Thus far all the units built are similar to Fig. 1 which is provided with 3-in. tubes throughout. The gas outlet temperature to the cascade from this unit is about 700 F and permits a corresponding solid content in liquor to the cascade down to 42 or 45 per cent. The unit shown in Fig. 5, which is designed for the ultimate in steam production, provides an additional pass of boiler tubes, space being acquired by using larger drums and substituting 2-in. tubes for the 3-in. tubes in the last two passes. Additional heating surface is provided by an economizer. The gas temperature to the cascade evaporator may be below 450 F and will require that the liquor be delivered

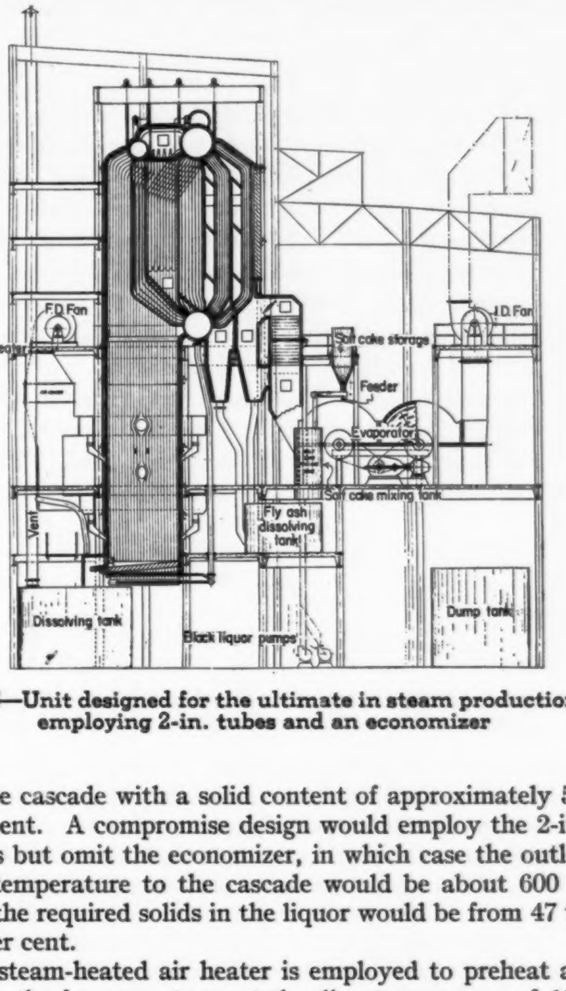


Fig. 5—Unit designed for the ultimate in steam production, employing 2-in. tubes and an economizer

to the cascade with a solid content of approximately 55 per cent. A compromise design would employ the 2-in. tubes but omit the economizer, in which case the outlet gas temperature to the cascade would be about 600 F and the required solids in the liquor would be from 47 to 50 per cent.

A steam-heated air heater is employed to preheat all air to the furnace, steam at the digester pressure of 125 to 150 lb being used.

Maintenance

It is too early in the history of operation of such units built with completely bare metal-walled furnaces to have accumulated maintenance figures. It seems certain, however, that this will be only a few cents per ton of pulp produced. The only exposure of refractory material is on the furnace bottom and indications to date are that the wastage of this material will be nil. After nearly three years of service on the original unit, walls show no deterioration. Maintenance and depreciation on the cascade evaporator are practically zero. The gases passing through this unit are slightly acid. The liquor however is highly alkaline and all surfaces are at all times thoroughly protected by a coating of this liquor. Some corrosion of duct work and fans beyond the evaporator will be experienced and will, no doubt, require their renewal after a period of years.

How the C-E Steam Tables Were Derived

By DR. ERICH F. LEIB

Combustion Engineering Company, Inc.

In a paper "Thermodynamic Properties of Vapors," presented at the Spring Meeting of the A.S.M.E., May 1940, and published in the Transactions of the A.S.M.E., February 1941, the writer introduced the "Perfect Vapor" as a convenient means of representing the properties of vaporous substances. This method which is described in detail in Sections 5 and 8 of the reported paper was used to prepare the steam tables issued by Combustion Engineering Company in August 1940. The following shows how these were prepared.

THE characteristic properties of the Perfect Vapor are summarized in the equation of state (equation 32 of the paper mentioned)

$$\frac{pv}{RT} = \frac{\vartheta_0^3/T^3v}{e^{\vartheta_0^3/T^3v} - 1} \qquad (1)$$

and in the relation between the calorific and thermal properties (equation 106 of the paper) which for a three-atomic vapor, such as steam, reads

$$h = 4pv + u_{osc} \qquad (2)$$

where p = absolute pressure, T = absolute temperature, v = specific volume, h = enthalpy, R = gas constant, ϑ_0 = empirical constant. The quantity u_{osc} is the energy of internal oscillation of the three atoms in the H_2O molecule and can with satisfactory accuracy be written as in the following equation;

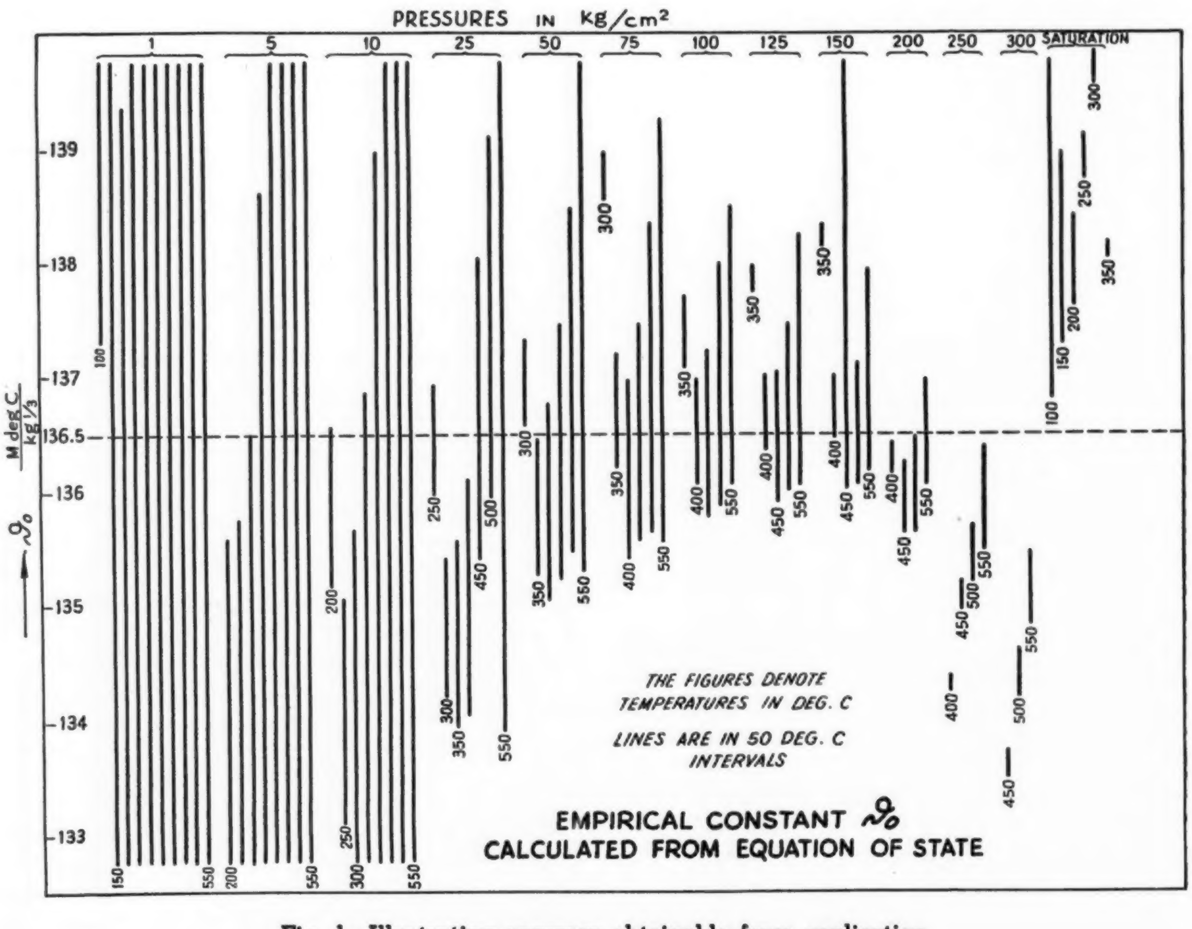


Fig. 1—Illustrating accuracy obtainable from application of equation (1) to steam

$$u_{osc} = R\left[\frac{\Theta_1}{e^{\Theta_1/T}-1} + \frac{\Theta_2}{e^{\Theta_2/T}-1} + \frac{\Theta_3}{e^{\Theta_3/T}-1}\right] \qquad (3)$$

where the constants Θ_1, Θ_2, Θ_3 have, in English units, the values

$$\Theta_1 = 4216 \text{ F} \quad \Theta_2 = 9643 \text{ F} \quad \Theta_3 = 9886 \text{ F} \qquad (4)$$

The accuracy obtainable from the application of (1) to steam is illustrated by Fig. 1, where the values of the empirical constant ϑ_0 are plotted, calculated from equation (1) for all states in the International Steam Tables of 1935. For each state, the highest and the lowest value for v, according to the allowed tolerance, have been substituted into (1), and pertaining values ϑ_0 are connected by a bar in the diagram. A line traced across the diagram at $\vartheta_0 = 136.5$ m deg C kg$^{-1/4}$ [620 ft deg F lb$^{-1/4}$] intersects with about two-thirds of all bars; this means that equation (1) with this value for ϑ_0 will satisfy the respective states within the limits of the tolerance which amounts from ± 1 to ± 2 parts in one thousand. In order to attain the required accuracy for all states, the quantity ϑ_0 was modified in the following manner: According to Fig. 1, the deviation of ϑ_0 from the average value is most pronounced for the saturated steam. Therefore, the saturated volume from the International Steam Tables was substituted into (1) and the resulting values ϑ_0^s were plotted against the pressure. The curve obtained can be represented by the equation

$$\vartheta_0^s = 633.70 - 0.02295\left[\left(\frac{p - 1300}{100}\right)^2\right]^{1.2} \text{ ft deg F lb}^{-1/4} \qquad (5)$$

where the pressure p is taken in pounds per square inch. A smooth transition from this value to the average value of ϑ_0 for superheated steam is provided for by the relation

$$\vartheta_0 = \vartheta' + (\vartheta_0^s - \vartheta')\left(\frac{\text{F}(p) - T/T_s}{\text{F}(p) - 1}\right)^2 \qquad (6)$$

where T_s = absolute saturation temperature at pressure p

$$\text{F}(p) = 1.195 - 0.0000422\, p \quad \text{empirical transition function} \qquad (7)$$

$$\left.\begin{aligned} \vartheta' &= 608 + \frac{p}{100} && \text{for } p < 1200 \text{ lb/in.}^2 \\ \vartheta' &= 620 && \text{for } p > 1200 \text{ lb/in.}^2 \end{aligned}\right\} \qquad (8)$$

Substitution of (5), (7) and (8) into (6) yields the modified values ϑ_0 which were used in order to obtain from equation (1) the correct volume for given pressure and temperature. This volume is then substituted in (2), to obtain the enthalpy for given pressure and temperature. In order to make the value of the enthalpy zero for saturated water at 32 F, a constant h_0 must be added to the right-hand side of equation (2). The average value of this constant is, in heat units,

$$h_0 = 858 \text{ Btu/lb} \qquad (9)$$

To obtain agreement with the International Steam Tables for all states, this quantity was likewise modified. The quantity h_0 was calculated for all enthalpy values in the International Steam Tables for saturated and superheated steam and plotted against the ratio pv/RT which can be considered a measure for the deviation from the perfect gas state (Fig. 2). The highest curve in Fig. 2 represents the limiting value of h_0 for a superheat higher than the increment between this curve and the next highest curve of constant superheat. The value h_0 from the lowest curve yields the enthalpy for the saturated steam in agreement with the International Steam Tables.

The volume of the saturated liquid was obtained by interpolation from the International Steam Tables, The enthalpy of the saturated liquid was interpolated from the International Steam Tables below 1600 lb per sq in. pressure and from the Bureau of Standards Research Paper 983 above this pressure. The latent heat

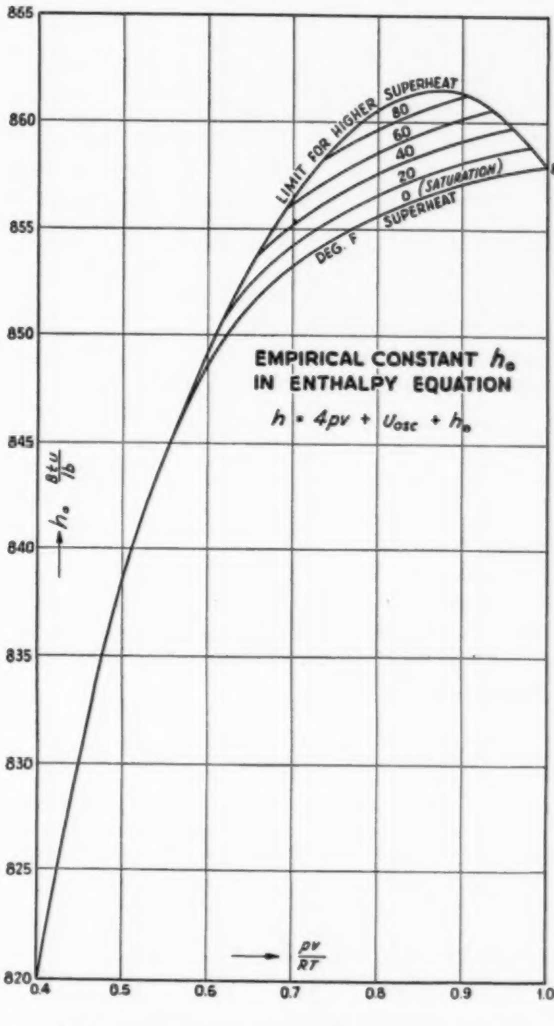


Fig. 2—Values of h_0 plotted against pv/RT

of evaporation, h_{fg}, was found as the difference between the saturation enthalpies in the liquid and vapor state.

The zero value of entropy is the saturated liquid of 32 F. Beginning with this state, the entropy for the saturation curve of the liquid was calculated for small increments of pressure from the relation

$$\Delta s = \frac{\Delta h - v_m \Delta p}{T_m} \qquad (10)$$

where the subscript $_m$ denotes the mean value for the respective interval. The entropy of the saturated steam was found by adding the quantity h_{fg}/T to the entropy of the liquid for the respective temperature or pressure. Starting from saturation, the entropy of the superheated

steam was calculated for small increments of temperature at constant pressure from equation (10) with $\Delta p = 0$.

The corresponding values of temperature and pressure for the saturation curve were obtained from the table for the quantity $T \dfrac{dp}{dT}$ in the Bureau of Standards Research Paper 983. For these values, an empirical formula was tried of the form

$$T\frac{dp}{dT} = \frac{p + b}{n}$$

or integrated

$$T = a(p + b)^n \qquad (11)$$

If T is taken in deg F and p in lb/in.^{2}, these constants were found as

$$a = 374.45 \qquad b = 160.67 \qquad n = 0.1398094 \qquad (12)$$

The vapor pressure curve calculated from (11) and (12) agrees with the tolerance prescribed by the International Steam Tables in the pressure range from 1150 to 2250 lb per sq in. For lower as well as higher pressures, an adjustment function $f(p)$ was added to the right-hand side of equation (11). This function was found to be

$$\left.\begin{aligned} &\text{for } p < 1150 \quad f(p) = -41.713e^{-0.0065991p} \\ &\text{for } p > 2250 \quad f(p) = -\left(\frac{p}{3393.63}\right)^{11.1213} \end{aligned}\right\} \qquad (13)$$

The saturation temperatures for pressures below 480 lb per sq in. were taken from the previous edition of the steam tables produced by The Superheater Company.

In order to compute the volume in the critical point two plots of the vapor pressure curve were made in those properties of state which are characteristic for the perfect vapor: $\vartheta = Tv^{1/3}$ and $\pi = pv^{4/3}$. In these coordinates, the two branches for the saturated liquid and the saturated vapor have a continuous transition in the critical point. In the International Steam Tables, the properties of state are given for both branches of the saturation curve up to a temperature 0.2 F below the critical point. If the curve is plotted in a π, ϑ diagram, the tangent to both branches approaches the slope of the perfect gas curve, $\pi = R\vartheta$, as the critical point is approached from both ends. If the curve is plotted in a $\pi^{1/4}/\vartheta, \vartheta$ diagram, the tangent to both branches approaches a horizontal line as the critical point is approached from both ends. It was assumed, that in the critical point these two tangents should exactly have the slopes R and 0, respectively. Then, the following two relations are obtained:

$$\frac{d\pi}{d\vartheta} = R \qquad \text{and} \qquad \frac{d}{d\vartheta}\left(\frac{\pi^{1/4}}{\vartheta}\right) = 0 \qquad (14)$$

The second equation in (14) can be written

$$\frac{d\pi}{d\vartheta} = 4\frac{\pi}{\vartheta}$$

which in conjunction with the first equation in (14) gives

$$\frac{\pi}{R\vartheta} = \frac{1}{4} \qquad \text{or} \qquad \frac{pv}{RT} = \frac{1}{4} \qquad (51)$$

Since R is the gas constant, p is known for the critical point, and T is obtained from equations (11) and (13), the critical volume v can be calculated from (15). Then, the enthalpy and entropy in the critical point were obtained in the manner described for the other points on the saturation curve.

STEAM ENGINEERING ABROAD

As reported in the foreign technical press

District Heating in Russia

According to A. E. Margolis in the February 1941 issue of *The Steam Engineer* (London), district heating in Soviet Russia forms a substantial part of the electrification program. The main argument advanced for combined heat and power generation is the increase in thermal efficiency, the severe climate and the relatively long period over which there is heating demand. Moreover, although Russia has large deposits of high-quality coal these are far removed from many of the larger cities and the railway transportation makes this coal expensive. On the other hand, poorer grades of coal are located nearer the industrial centers, and this can be burned better in large central stations than in individual factory or heating plants.

Starting from a small beginning in Leningrad in 1924 with two service lines approximately 750 ft long, the steam distribution system in that city had grown to 44 miles of mains by 1938. Similar growth is cited in Moscow and numerous provincial towns.

According to the current five-year plan the capacity of steam power stations will have been increased to seven million kilowatts by 1942, of which five million will be in back-pressure or extraction turbines supplying steam for public heating.

Automatic Record of the Hydrogen Ion Concentration

In *VDI Zeitschrift*, Vol. 84, No. 40, Dr. Arthur Kuntze describes a device which automatically produces a record of the hydrogen ion concentration in any solution. The principle upon which it operates is as follows:

There is a relation between the hydrogen ion concentrations and the electromotive force existing between two electrodes immersed in solutions of different concentrations. By equating the work which two solutions of different concentrations can produce by their osmotic pressures and the electric work which results from the electromotive force present and the current flowing, Nernst found that the electromotive force $E = 0.058 \log C_1/C_2$, where C_1 and C_2 are, respectively, the pH concentrations of the measured solution and the comparing solution, at a temperature of 18 deg Centigrade. If the solutions into which the suitable electrodes are dipped differ by pH = 1, then the pH concentrations are in relation of 10:1 and there is an emf of 57.7 millivolts between electrodes, if the temperature is 18 deg.

This value may be determined by trial. The container *c* of Fig. 1 will serve illustratively. Between the solutions *g* and *h*, which vary in pH concentration, there is a membrane *k* which has fine pores. The measurements of the emf across the electrodes *l* and *m*, in a currentless state, is determined by the aid of a compensating device, an electrometer, or a tubular voltmeter.

This sketch shows a basic hookup for an electrometer including an indicator with four quadrants which deviate the needle *a* that is alternately connected by means of switch *b* to the ground (position II) and via the glass electrode *c* and potentiometer *d* to the ground (position I). The pair of quadrants e_1 and e_2 are continuously connected to the poles of battery *f*, whose mid-point is grounded. The potentiometer *d* is moved until there is no needle movement when switch *b* is connected to either position I or II. The electromotive force present at the glass membrane is then read on the potentiometer setting *d*.

A new automatically recording pH measuring device has been developed for all dilute fluid solutions of from

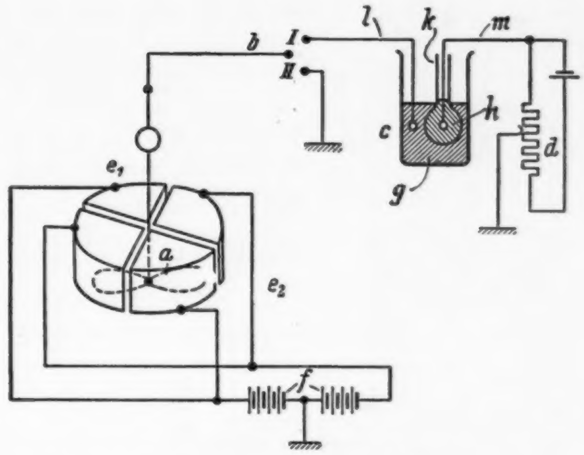


Fig. 1—Basic hook-up for measuring pH value with an electrometer

a—Electrometer needle
b—Switch
c—Glass electrode
d—Potentiometer
e_1e_2—Quadrant pair
f—Battery

15 to 40 deg Centigrade. It consists of a glass membrane and two saturated calomel electrodes as pH indicators and a highly sensitive Lindeck-Rothe compensator as receiver.

The hookup is shown in Fig. 2. The glass electrode is provided with an arrangement for continuous drop feed and removal of the solution to be measured. The electron tube *a* serves as a variable resistance and influences the anode current i_a in such a way that its voltage drop at resistance *b* is nearly equal to the potential difference E_1 resulting from the difference in pH value between the measured and the comparing solution. The grid of the electron tube is influenced by a gas-filled photocell *c*, which contains a cathode of caesium-caesium oxide (C_s-$C_{2s}O$) on a silver mounting.

The life of the parts of this hookup is stated as being very high. The light falling onto the photocell is rela-

tively small and the light source is carried below normal voltage. The loading on the electron tube is chosen half of that permissible.

Because of the small righting force in the galvanometer there is an incomplete balance with the measured voltage at resistance *b;* that is, an approximation of the

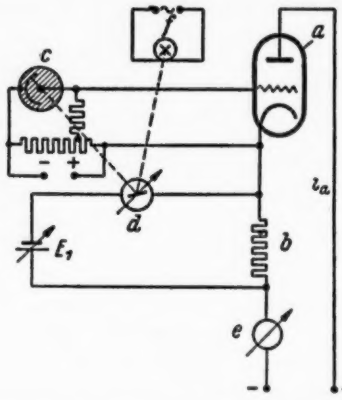


Fig. 2—Automatic balancing, light-electric, Lindeck-Rothe Compensator

a—Electron tube
b—Compensating resistance
c—Photocell of the automatically balancing compensator
d—Zero galvanometer
e—Recorder
f—Illumination
E_1—The voltage differential due to the difference in pH value
i_a—Anode current

value at zero balance and the closer the deviation from true balanced condition, the less the error. The zero setting for the galvanometer *d* is such that the mirror reflects the necessary light onto the photocell for the mid setting of the recorder and in this way reduces the error of deviation by half.

To compensate for temperature influences between the solution being measured and the resistance *b*, the latter may be made of platinum cast into a quartz glass and so placed in the solution that it assumes the same temperature.

Five-Year Power Development Plan in Manchoukuo

According to *The Far Eastern Review* of January 1941, the government in Manchoukuo has initiated a five-year plan of power development. Several years ago the various power companies, owned by local and by Japanese interests, were merged into a government-controlled company, the Manchuria Electric Corporation, through which the present plans for development are to be carried out.

Unlike Japan, most of the electricity in Manchoukuo is at present produced by steam of which over 600,000 kw capacity is installed. The five-year plan calls for an increase to about two million kilowatts capacity, a large part of which will be hydro, resulting from the construction of dams and reservoirs on several large rivers to combine stream control, navigation improvement, irrigation and power development.

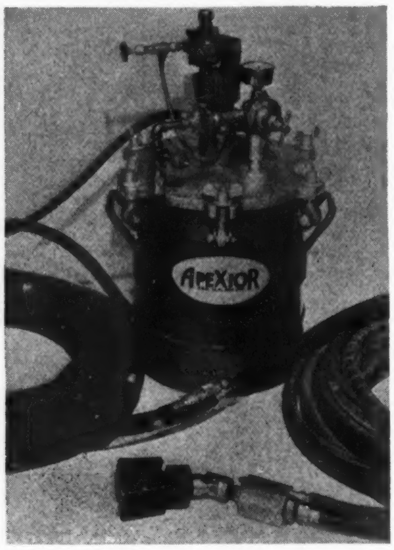
Coal deposits in Manchoukuo are estimated at from 20 to 30 billion tons, of which about ten million tons are mined annually. As the output increases to meet industrial demand, there will be more mine refuse available, which it is planned to utilize for steam generation.

NEW EQUIPMENT

Coating Machine for Boiler Tubes

For applying protective coatings to the interior of boiler, economizer, condenser and other accessible tubing, the Dampney Company of America has developed a new automatic tube-coating machine which is reported to reduce the coating time as well as improve the quality and uniformity of coverage.

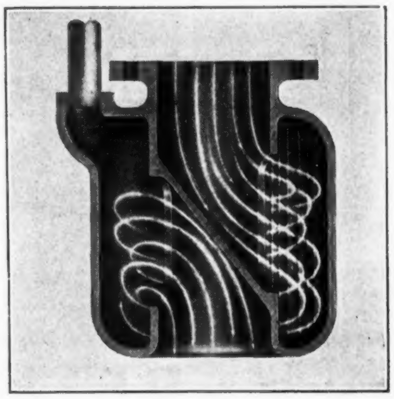
This equipment, shown in the illustration, consists of a pressure-feed Apexior container equipped with adjustable coating-pressure regulation. It operates with



air-motor agitation employing a single air-fluid line and forced feed to the expanding brushes through a specially constructed air turbine. With operating hose lengths up to 150 ft or more, connected to a working line up to 75 ft long, the operator is able to pass the brush head all the way through the tube. The coating is discharged into the path of the rotating brush as the coating unit is withdrawn. This method is said to help the handling of long horizontal, bent or vertical tubes with considerable saving in both labor and material. The machines are available either for purchase or rental.

Exhaust Head

A new exhaust head, incorporating the principles of the baffle-type separator as used for removing oil and moisture from steam lines, is announced by the Cochrane



Corporation. In the design shown the steam is whipped sidewise and causes projection of entrainment against rubbed baffle surfaces. The large port area produces low steam velocity and minimizes pressure loss. The exhaust head is of one piece semi-steel construction for the 4- to 12-in. sizes and of welded plate for the larger sizes. In all, eight sizes are available.

Plastic Charts

An improved design in recording instrument charts for continuous re-use has been developed by the Permochart Company. Made of plastic, the chart can be constantly re-used, as the previous day's ink record is easily removed from its surface with a damp cloth. The material is non-flammable and is resistant to oil or grease. Because of the repeated use the chart centers are now reinforced to prevent deterioration and the printing and laminations have been improved to prevent separation at the edges. Each chart is guaranteed for daily use over a period of two years.

Where it is necessary to save chart records, a microfilm photographic outfit is available for recording and filing with accompanying large reduction in filing space.

Portable Water Testing Outfit

Betz Laboratories announce a complete portable plant laboratory for making such water analysis as hardness, alkalinity, chlorides, sulphates, phosphates, pH and iron. The outfit weighs approximately fifty pounds and the apparatus and chemicals, together with a fluorescent light, are compactly arranged in a $23^1/_2 \times 22^1/_8 \times 8^3/_{16}$-in. cabinet, provided with a duck cover for protection.

Unit Heater

"Downblast Speed Heater" is the name of a new unit heater developed by B. F. Sturtevant Company. As the name implies, the heat is projected directly downward at high velocity and it is thus particularly suited for buildings with high ceilings, although if it is desired for a comparatively low installation deflection cones are left in place to afford wider diffusion of the heated air stream.

The heater consists of a circular extended-surface heating element protected by a screen guard, with copper tubes brazed into copper headers forming a homogeneous unit. The room air is drawn into the heater over the heating coil and projected downward by a fan, and headers on both sides of the coil permit rapid cleaning of condensate. Twelve sizes are available ranging from 40,000 to 400,000 Btu per hr.